NITROGEN USE EFFICIENCY OF RICE AS AFFECTED BY THE TYPE OF UREA FERTILIZERS AND SOIL PROPERTIES IN BURKINA FASO

BY

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SEPTEMBER, 2014

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

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SCHOOL OF GRADUATE STUDIES

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A Thesis presented to the Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, in partial fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

SEPTEMBER, 2014

DECLARATION

I hereby declare that this submission is my own work toward the PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

The loss of nitrogen (N) can be very high in rice (*Oryza sativa* L.) fields, particularly in the irrigated rice cropping systems with very poor water control. Previous studies have reported low (30%) N use efficiencies (NUE) using broadcast application method of fertilizer N (Urea) in irrigated cropping systems. This low N use efficiency is associated with low yields. This thesis is addressing strategies to increase NUE and rice yields in irrigated system. The effect of urea fertilizer type (prilled urea and urea supergranule) on rice yield performance was investigated in five studies. Field and pot experiments were carried out in a pilot irrigated scheme of Sourou valley located in the north western part of Burkina Faso. The studies were conducted in 2012 and in 2013. The main objective of the study was to optimize nitrogen use efficiency of irrigated rice production by reducing losses from rice field. The amounts of total nitrogen, phosphorus and potassium uptake increased in the rice plant with the use of urea supergranule compared to prilled urea during the different rice growth stages. Acid soil recorded higher N, P and K uptake compared to alkaline soil. Maximum nutrient uptake was observed at flowering stage. Soil total N content was higher with the use USG in acid soil than alkaline soil. Root development and the number of tillers increased with the use of USG in acid soil compared to alkaline soil. The highest and lowest ammonium concentrations in floodwater were recorded with the use of PU at 26 kg N ha^{-1} (2.8 mg l^{-1}) and USG at 52 kg N ha^{-1} (2.26 mg l^{-1}) in the wet season of 2012. The overall concentration of ammonium in floodwater was higher with the use of PU (1.34 mg l^{-1}) than USG (0.98 mg l^{-1}) during the wet season of 2013.

The increases in grain yield following urea deep placement with USG were 8 to 18% relative to broadcasting method with PU. The straw yield increased with the use of USG relative to PU also ranged from 10 to 27% during the three cropping seasons. The use of USG with FKR 62N produced the highest numbers of tillers and panicles, leading to higher yields. The application of USG increased grain N uptake by 3%, P uptake by 6% and K uptake by 80% over PU in the wet season of 2012. The increase in grain N, P and K uptake with USG over PU were 25, 16 and 42 %, respectively in the wet season of 2013. The highest grain N and P uptake was obtained with USG. The agronomic efficiency (AE) significantly by 39 and 46% increased with USG application in the two wet seasons. The physiological efficiency (PE) and recovery efficiency (RE) varied between rice varieties during the three seasons. During the dry season AE, PE and RE were not significant with the use of urea fertilizers. The combined effect of USG and phosphorus did not affect rice yield. The increases in grain yield with phosphorus application relative to the control ranged from 25 - 107% during the wet and dry seasons and the highest yield was recorded at 50P. The increases in AE with USG 1.8 g over USG 2.7 were 48.93% in the wet season of 2012 and 24.43% in the dry season of 2013.

DEDICATION

This Thesis is dedicated to my parents Allassane Bandaogo and Habiba Zampou for their never ending love.

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God bless all of US.

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LIST OF ACRONYMS

AGRA	Alliance for Green Revolution in Africa
BCI	Better Crop International
BRRI	Bangladesh Rice Research Institute
CEFCOD	Centre d'Etude, de Formation et de Conseil en Développement
CFA	Communauté Financière d'Afrique
CIPAM	Compagnie industrielle de production agricole et marchande
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pourle Développement
DAT	Days after transplanting
DCD	Dicyandiamidate
EDTA	Ethylene diaminetetraacetic acid
FAO	Food and Agriculture Organization of the United Nations
FKR	FaraKobà Riz
GRET	Groupe de Recherches et d'Echanges Technologiques
IFDC	International Fertilizer Development Center

INERA	Institut National d'Environnement et de Recherche Agricole
ISFM	Integrated Soil Fertility Management
KCl	Muriate of Potash
Lsd	Least significant difference
MAHRH	Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques
NUE	Nitrogen Use Efficiency
OECD	Organisation for Economic Co-operation and Development
PI	Panicle Initiation
PPD	Phos- phorodiamidate
PU	Prilled urea
USG	Urea supergranule

CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa* L) is among the major crops in Burkina Faso and it is rated as the fourth most important cereal after millet, sorghum and maize (Sié *et al.,* 1998). The national production is still low and cannot satisfy the demand, causing the government to spend about 30 billion CFA on rice importation annually. Yields of rice vary greatly and the average grain yield is 1.3 ton ha^{-1}. Domestic production of paddy rice was 195,102 tons in 2008; 249,063 tons in 2011 and 319,390 tons in 2013 (CEFCOD, 2013). Currently, national production covers 42% of the demand and 58% is met from imports (CEFCOD, 2013). The demand for rice is constantly increasing and is estimated to reach 825,000 tons in 2015. This situation requires an increase in production through yield improvement (MAHRH, 2010). Irrigated lowlands constitute only about 23% of the total rice area; this system is characterized by higher yields and contributes about 53% to national rice production (INERA, 2010). Irrigated rice is a production system that can gives high levels of returns, but nitrogen is the main factor limiting yields of these systems (Segda, 2006). The use of urea and urea fertilizers has increased considerably over the past 15 years and currently accounts for approximately 51% of the world's agricultural nitrogen (N) consumption (Anonymous, 2006). Wood *et al*. (2004) estimated that 50 to 70% more cereal grain would be required by 2050 to feed 9.3 billion people. This would require increasing N fertilizer to the same magnitude (50 - 70%). However, as N use efficiency (NUE) generally declines with increased fertilizer use, the requirement may even double, as projected by Wood *et al*. (2004).

Urea is not only the solid fertilizer with the largest percentage of nitrogen at present, but is also one of the least expensive sources of N for crop production. Management of nitrogen fertilization is an important factor in productivity and profitability. However, the current system of fertilization causes about 60 to 70% of the N applied to be lost (Morales *et al.*, 2000). These losses are due to several causes that include the form of N fertilizer, mode of application, varietal differences, soil characteristics and cropping systems (Wang *et al.*, 2010). Only 30 - 40% of fertilizer N applied by conventional broadcast method is available for plant growth; the rest of the N is subject to losses through ammonia volatilization, denitritification, leaching, runoff, and biological or chemical immobilization (Craswell *et al.*, 1981; Ladha *et al.*, 2005). Numerous researchers have reported that recovery of applied N by lowland, rainfed and irrigated rice is invariably low and hardly exceeds 50% (Tilman *et al.*, 2002; Dobermann and Cassam, 2004). Yields have substantially increased but remain below the varieties yielding potential; and more fertilizer is used while NUE remains very low (Wopereis *et al.*, 1999). This low recovery is attributed to losses of N from soil - water - plant system due to ammonia volatilization, nitrification-denitrification, leaching, and runoff and NH_4^+ fixation by clays (Cao *et al.*, 1984; Singh and Buresh, 1994). This poor efficiency is of great concern for a number of reasons: even if the efficiency of nitrogenous fertilizers remains at the present level, the losses will increase enormously as their consumption is expected to double within the next 25 – 30 years; their manufacture involves high - cost technology. The best method widely available to farmers for applying N to rice is to broadcast the fertilizer in split doses; this method is recommended by many extension agencies. As it was previously stated this method has many limitations. However, opportunities exist for improving fertilizer efficiency in most countries, and cooperation between the international research centers and national agricultural research organizations is speeding the process of transferring fertilizer technology. Urea Supergranules (USG) or urea briquettes are promising materials for smallholder farmers in West Africa because their large size particles can be effectively deep placed by hand. Urea Deep Placement (UDP) technology has proved to be highly effective in improving crop uptake of applied nitrogen fertilizers in irrigated rice system in Asia (Bowen *et al.*, 2004; Pasandaran *et al.*, 1999) and therefore, merits to be experimented in similar production systems in Africa. Unfortunately, information on the response of irrigated rice systems to the technology of fertilizer deep placement with urea supergranule is very limited, particularly where the crop is subjected to flooding and/or higher depths of standing water. Furthermore, irrigated rice cropping systems must emphasize the maintenance of available soil nutrients to ensure that soil P supply does not limit crop growth and thus reduce N use efficiency. Therefore, this study was initiated with the main objective of **optimizing nitrogen use efficiency of irrigated rice production by reducing N losses from rice field.**

The specific objectives were to:

i. assess the effect of urea fertilizers on rice root growth, soil nitrogen content, nitrogen uptake in acid and alkaline soils;

ii. quantify the effect of urea fertilizers on ammonium concentration in floodwater;

iii. evaluate the effect of urea fertilizers on rice growth, grain yield and nitrogen use efficiency of rice varieties and

iv. determine the effect of rate of phosphorus on nitrogen use efficiency of USG.

Hypothesis

i. The technology of urea superranules can increase rice root growth, soil N content and N uptake in acid and alkaline soils.

ii. the technology of urea supergranules can reduce ammonium concentration in floodwater relative to prilled urea.

iii. the technology of supergranules can increase nitrogen use efficiency and rice yield in comparison to prilled urea.

iv. Increasing rate of phosphorus fertilizer increases the NUE of USG.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and ecology of rice

Rice (*Oryza sativa* L) is a grass (Gramineae) and belongs to the genus Oryza (meaning oriental). Rice was first grown in south - east Asia, India and China between 8000 and 15 000 years ago (Normile, 2004). The genus Oryza contains 21 wild species of the domesticated rice (Vaughan *et al.*, 2003). The genus is divided into four species complexes: *O. sativa, O. officialis, O. ridelyi* and *O. granulata* s. The *O. sativa* complex contains two domesticated species: *O. sativa* and *O. glaberrima*. *Oryza sativa* is distributed globally with a high concentration in Asia while *O. glaberrima* is grown in West Africa. Rice cultivars can vary widely in length, width, colour and leaves pubescence. A large number of *O. sativa* have been developed through centuries of rice domestication. Currently, the cultivation of rice is worldwide. Cultivars can be divided into three ecological varieties, indica (tropical and sub-tropical distribution), japonica (temperate distributions) and japonica is grown in Indonesia. Rice can be grown under a variety of water regimes, such as unsubmerged upland rice, moderately submerged lowland rice, and submerged rice. Rice can also be cultivated on a wide range of soil types, including saline, alkaline and acid sulphate soils (Ahn *et al.*, 1992; OECD, 1999). Temperature below 18 °C at night during pollen formation results in sterile pollen in all rice cultivars (Mc Donald, 1994). In paddy rice, maximum yields are obtained in the dry season, when cloud cover is less and photosynthetic active radiation is greater than during the wet season (BCI, 2002).

2.2 Nitrogen requirements of rice

Nitrogen is the most essential element in determining the yield potential of rice (Cassman *et al.,* 1996). Rice plants require N as much as possible at early and mid tillering to maximize panicle. Nitrogen is also needed at the reproductive and ripening stages to increase the number of spikelets per plant and the percentage of filled spikelets (De Datta *et al.,* 1986). The estimated amount of N removal ranges from 16 to 17 kg (Table 2.1) for the production of one ton of rough rice, including straw (Choudhury *et al.,* 1997; Sahrawat, 2000; Dobermann and Fairhurst, 2000). The efficiency of nitrogen uptake varies from 20 to 60 % depending on the conditions (soil type, water control, pH and water temperature), doses and modes of supply (split or not) and varieties (CIRAD-GRET, 2002). Ammonium production is essential in the nutrition of irrigated rice (Gaudin, 1991), although rice can also remove the nitrate-N (Narteh and Sahrawat, 1999). Ammonium-N fertilizer sources are recommended because the $NH4^{+}$ is stable under flooded soil conditions (Snyder and Slaton, 2002).

Table 2.1: Nitrogen uptake and N content of modern rice varieties.

Plant part	Typical N observed range (kg N uptake t^{-1})	% N content
Grain + straw	15 – 20	-
Grain	9 – 12	0.93 – 0.76
Straw	6 – 8	0.51 – 0.76
Unfilled spikelets	-	0.76 – 1.02

Source: Dobermann and Fairhurst (2000)

2.3 Dynamics of nitrogen under irrigated systems

Irrigated systems constitute an anaerobic area because of the presence of floodwater, where reduction often takes place (Dobermann and Fairhurst, 2000). Floodwater constitutes an obstacle to the recharge of soil oxygen and gaseous diffusion is 1000 times slower in water than aerobic area (Condom, 2000). Flooded rice fields undergo a unique sequence of chemical and microbial transformations related to the changes in soil water content that occur during a cropping cycle. It is necessary to understand these processes to optimize the management of N and other nutrients. Under submerged soil urea is highly prone to ammonia volatilization due to the hydrolysis to NH_4^+. When urea is applied to the soil, it reacts chemically with water (hydrolysis) and urease enzyme to produce carbonate, an unstable compound that can quickly decompose to NH_3 gas. The urease enzyme needs to be present and active to produce the hydrolysis of urea. The common urea hydrolysis reaction is as follows (Merigout, 2006):

$$\boldsymbol{CO(NH_2)_2 + H^+ + 2H_2 0 \xrightarrow{Urease} 2NH_4^+ + HCO_3^-}$$

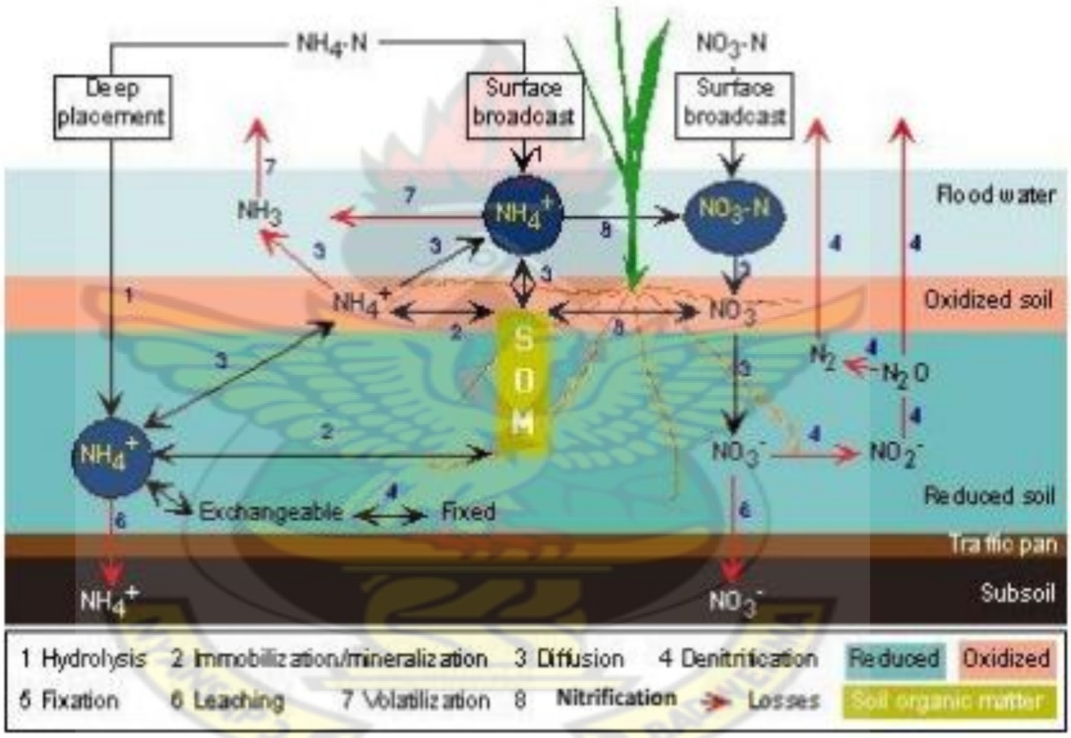
2.3.1 Factors influencing hydrolysis of urea

There are many factors that affect the hydrolysis of urea: soil organic matter content, soil water content, temperature, etc. Urea hydrolysis rates are higher at higher temperatures, and NH_3, like all gases, is more volatile at higher temperatures. High levels of soil organic matter and crop residues increase urea hydrolysis rates and volatilization. This is largely because the urease enzyme, which is necessary for hydrolysis, is produced by microorganisms that are more active in the presence of organic material than in mineral soil. Residue may also prevent urea and its hydrolysis product (NH_4^+) from entering the soil (Jones *et al.,* 2007). A very high concentration of urea can also inhibit hydrolysis.

2.3.2 Fate of urea in floodwater

Several distinct layers are observed in paddy rice soils following flooding (Figure 2.1). Flooded zone varies in depth (1 – 15 cm) and this layer is colonized by bacteria and algae which contribute to biological N fixation. The surface of this zone also increases with the submersion duration (Chowdary *et al.,* 2004). Beneath this zone, a thin layer of oxidized soil (usually < 10 mm) remains oxidized after flooding because of the diffusion of O_2 (Dobermann and Fairhurst, 2000).

This oxidized layer promotes the development of microorganisms and their numbers increase during submersion. When ammonium-N fertilizer (e.g. urea, ammonium sulphate) is broadcasted into the floodwater, N hydrolysis and nitrification take place in the oxidized zone (Mosier *et al.,* 1990). NH_4^+ ions diffuse into the oxidized soil following hydrolysis and are absorbed by the rice plant either directly or following nitrification, or become temporally immobilized in soil organic- N pool. After nitrification of NH_4^+-N in the oxidized layer, NO_3^--N is either taken up by rice root or leached into the reduced soil layer, where it is denitrified and is lost as ammonia by volatilization and N_2 gas by denitrification (Dobermann and Fairhurst, 2000). Flooded soils are anaerobic area where ammonification process is more than nitrification. The main source of nitrogen supply is ammonia (Gaudin, 1991). The inefficient recoveries of N by plants are caused by nitrate leaching and emissions of N_2O and NOx gaseous forms from agricultural soil with health and environmental implications (Whitehead, 2000). Below the oxidized layer lies the bulk soil. This layer is a reduced zone where activities of anaerobic soil microorganisms that use nitrate take place. When, ammonium- N fertilizer is placed in the reduced layer (deep placement) urea hydrolysis is quick. The resulting NH_4^+ ions are absorbed by the rice root or are leached into the subsoil or temporarily immobilized in the soil organic-N pool or adsorbed on the exchange complex.



(Adapted from Dobermann and Faihurst, 2000)

Figure 2.1: Nitrogen dynamics in irrigated systems

2.4 Ammonia losses

Ammonia volatilization is one mechanism that can significantly reduce nitrogen fertilizer efficiency. The rate of NH_3 volatilization depends on the rate of urea hydrolysis (urea's conversion to NH_4^+), weather conditions following application, and several soil properties (Jones *et al.,* 2007). Denitrification is probably the major mechanism by which nitrogen is lost from waterlogged soils, although volatilization losses of ammonia can occur under special conditions. Factors contributing to denitrification include pH, temperature, organic matter, wet/dry cycles, and fertilizer management (Dobermann and Fairhust, 2000). Ammonia volatilization from urea fertilizer is the major pathway of N loss in tropical flooded rice fields, often causing 50% or more of the applied urea-N (Bouman *et al*, 2007). Ammonia losses from urea broadcast on pastures have been reported to be as high as 29% of the N applied (Eckard *et al.,* 2003). Ammonia volatilization losses are important for both agricultural and non-agricultural ecosystems because they represent a direct loss of plant available N (Asman *et al.,* 1994). Concerns have been raised about the economic and environmental impacts of ammonia (NH_3) loss through volatilization when urea-base fertilizers are surface applied. Several factors influence nitrogen volatilization. During volatilization, physical, chemical and biological processes in soil are involved and plant may or may not influence ammonia losses (Hutchinson *et al*., 1972).

2.4.1 Soil pH and soil temperature

The conversion of NH_4^+ to NH_3 is governed by soil pH. During urea hydrolysis the pH surrounding the granule initially rises (pH > 8) as ammonium bicarbonate is formed. Ammonia (NH_3) volatilization is more likely during this period of hydrolysis (Mikkelsen, 2009). High soil pH and high temperature cause higher rates of NH_3 volatilization because they increase soil concentrations of NH_3 dissolved in soil water. This is one reason why applying urea during periods with forecasted cool temperatures is recommended to reduce volatilization, especially on high pH soils. The pH increase resulting from urea hydrolysis is temporary because NH_4^+ is converted relatively quickly to NO_3^- (nitrification), or NH_3; processes that lower pH by releasing H^+ ions (Jones *et al.*, 2007). However, the temporary increase in soil pH can result in NH_3 volatilization from soils with an initial pH as low as 6.5. Volatilization can also occur at soil pH below 6.5 if the soil buffering capacity is low.

2.4.2 Soil moisture and depth of urea in soil

Volatilization of topdressed urea increases linearly as soil water content increases, until the soil reaches saturation. Conversely, volatilization decreases dramatically as urea is moved below the soil surface, either through incorporation or movement by rainfall or irrigation (Jones *et al.*, 2007).

2.5 Strategies to increase nitrogen use efficiency (NUE)

The NUE is a complex term with many components, and can be defined as the yield produced per unit of N applied, absorbed, or utilized by the plant to produce grain and straw (Ladha *et al.*, 2005; Cassman *et al.*, 2002). Accurate estimate of NUE is very important and can help in devising new management practices to accurately estimate projected amounts of fertilizer N needed and to meet the increasing worldwide food demand. The three regularly used efficiency terms are the

Agronomic Efficiency (AE), the Recovery Efficiency (RE) and the Physiological Efficiency (PE) that are commonly calculated by the N difference method, also referred to as the N balance or the apparent N efficiency of applied-fertilizer-N method (Ladha *et al.*, 2005). The efficiency of N fertilizer is very low and one of the main reasons for the poor efficiency of fertilizer N is that much of the N applied (up to 92%) can be lost from the plant–soil system. Many strategies have been developed to increase NUE because of the low N efficiency in irrigated system. A number of management strategies have been developed to improve the efficiency of utilization of nitrogenous fertilizers and these include application of different types of fertilizers, their mode of application, avoiding runoff, mitigation of losses from soil and plants. They also include slow-and controlled-release fertilizers (i.e. fertilizers characterized by slow hydrolysis of water soluble compounds or those that have controlled water solubility due to semi-permeable coatings or other chemicals) and stabilized nitrogen fertilizers (i.e. fertilizers to which stabilizers like nitrification and/or urease inhibitors have been added) (Mohanty *et al.*, 1989; Yadeda and Juskiw, 2012). Nitrification inhibitors like dicyandiamide (DCD), iron pyrite, nitrapyrin, phenylacetylene, encapsulated calcium carbide and terrazole can be used to reduce losses from denitrification (De Datta, 1981; Freney *et al.*, 1995). Urea Supergranules (USG) or urea briquettes are promising fertilizer materials for West African smallholder farmers. It is a simple and low cost technology, well suited to small scale rice production and can also be locally produced by rice farmers to their benefits (Bowen *et al.*, 2004).

2.5.1 Fertilizer deep placement

Deep placement of N fertilizers into the anaerobic soil zone is an effective method to reduce volatilization losses (De Datta, 1981). Urea can be deeply placed into a reduced layer at 7- 10 cm soil depth. Urea supergranule (USG) is a compacted form of urea at different sizes developed by International Fertilizer Development Center (IFDC) (Savant and Stangel, 1990). Its granule size is bigger and condensed with some conditions for slow hydrolysis. USG is spherical in shape containing 46% N and is similar to that of PU. It is not a slow release fertilizer but can be considered as a slowly available N fertilizer. The use of USG has one great advantage because it requires only one time application after rice transplanting, whereas surface application of prilled urea requires two or three split applications, which can lead to ammonia losses (Chien *et al.,* 2009). The use of urea supergranules could synchronise N release with plant requirements and provide sufficient N in a single application to satisfy plants' requirements while maintaining low concentrations of mineral N in the soil throughout the growing season (De Datta and Patrick, 1986). The transport of ammonium from the placement site is slow because it is mainly a diffusion process influenced by ion-exchange (Gaudin, 1987). As a result, the spatial concentration gradients of available ammonium tend to exist in a restricted soil volume. The use of these fertilizers has generally decreased the total loss of fertilizer N (Choudhury *et al.,* 1997). The objective of these fertilizers is to make the amount of N released coincide with the N requirement of growing plants, especially the tillering and heading stages, and thereby reduce N losses. Placement forces urea into the anaerobic soil layer, thereby eliminating losses due to denitrification; decreasing diffusion of N into the floodwater and hence reduced NH_3 volatilization loss and runoff losses of N; and establishing better fertilizer - root contact and reducing weed competition (Singh, 2005; Cai *et al.,* 2002). Craswell and Vlek (1979) reported that the use of supergranules resulted in a significant increase in rice yield by 42% over broadcast prilled urea (PU). Depending on agroclimate and N rates used, urea deep placement (UDP) can help to provide a saving of urea fertilizer of up to 65% with an average of 33% and can help to increase grain yields up to 50% over that of the same amount of split-applied N as PU (Savant and Stangel, 1990).

2.5.2 Factors influencing nitrogen release

Urea can be encapsulated in various coatings or treated with chemicals to inhibit transformations of urea (Ramananda *et al.,* 2014) that result in N losses. The goal of fertilizer coatings is to slow the rate at which granules dissolve, and hence reduce losses. They delay the availability of a nutrient for plant uptake or extend its availability to the plant longer than rapidly available nutrient fertilizers. To ensure that urea is released over an extended period of time, granules are coated with sulphur layers of varying thickness. Nitrogen release from sulphur-coated urea depends on soil moisture and temperature. Chemical compounds can also be added to urea fertilizers to inhibit transformations of N.

Urease inhibitors are one class of compounds that prevent the conversion of urea to NH_4^+. Urease inhibitors offer great promise for reducing N losses. The aim of urease inhibitor is to extend the time the N component of the fertilizer remains in the soil in the urea or ammoniacal form. One compound in particular, phenyl phos-phorodiamidate (PPD) has been identified as a very effective inhibitor. The presence of PPD delays the disappearance of urea in the floodwater from 3 days to 7 days

(Youngdahl *et al.*, 1986; Fillery *et al.*, 1986). Inhibitors can delay the hydrolysis of urea for 2 to 10 weeks. In general, the longevity of urease inhibitors declines as soil temperature and moisture content increase (Jones *et al.*, 2007). Urease and nitrification inhibitors can reduce N losses, increase yields, and improve crop quality and management flexibility.

2.6 Effect of soil pH on nitrogen availability

Soil pH is a critical indicator of nutrient availability. Soil reaction is not a growth factor as such but it is a good indicator of several key determinants of growth factors, especially nutrient availability. The optimum pH for rice growth ranges between 5.5 and 7.0 (FAO, 2006). Management practices with long term use of ammonium-based fertilizer can induce soil acidity. Generally, soil acidity is not a major problem, unless the pH is very low (e.g. pH < 4) (Fairhurst, 2012). Different nutrients are available at different pH levels. Phosphorus is available at a slightly acidic or neutral pH. High soil pH is also known to affect the efficiency of N fertilizers. As the pH rises, an increasing fraction of soil N is converted from stable ammonium to gaseous ammonia, which can be lost to the atmosphere (Ernst and Massey, 1960). The study of Xiang *et al.* (2009) on aerobic rice cultivation reported that the decline in rice yield was associated with the reduction in soil N availability and plant N uptake following an increase in soil pH. However, in alkaline soils N volatilization as NH_3 losses can be important. High soil pH and high temperatures cause higher rates of volatilization because they increase soil concentrations of ammonia dissolved in soil water. Deep placement of urea supergranules has been shown to effectively reduce N loss and increase rice yield on near neutral pH soils with alkaline floodwater (Singh, 2005; Cai *et al.*, 2002). However, floodwater also increases pH in acid soils and decrease pH in alkaline soils (Dobermann and Fairhurst, 2000). Soils that are high in clay and organic matter have a high buffer capacity. Therefore, soil pH increases and ammonia volatilization losses are minimized in these soils. Sandy soils generally have low buffer capacity, therefore, pH increases and ammonia volatilization can be substantial.

2.7 Importance of nitrogen and phosphorus mineral fertilizers in irrigated rice systems

Low soil fertility, particularly nitrogen (N) and phosphorus (P) deficiencies, is one of the main factors restricting agricultural productivity in sub-Saharan Africa (Smaling *et al.*, 1997; Sanchez *et al.*, 1997). Kpoda (2013) through some omission trials in the Sourou valley revealed that these two nutrient elements are becoming limiting in this part of Burkina Faso. It has been shown that N efficiency was particularly higher when plant had sufficient phosphate and potash. Nitrogen and phosphorus fertilizers are major essential plant nutrients and key input for increasing crop yield (Dastan *et al.*, 2012; Yoseftabar, 2012). Nitrogen and phosphorus are fundamental to crop development because they form the basic component of many organic molecules, nucleic acids and proteins (Lea and Miflin, 2011). Phosphorus availability for rice in paddy soil varies depending on soil-water regimes (Kirk *et al.*, 1990; Bell *et al.*, 2001) but flooding generally increases the availability of P to rice crops. In irrigated rice system, phosphorus is generally applied before or during transplanting, this indicates that P is required during the early growth stages (Haefele and Wopereis, 2005; Hossain *et al.*, 2005). Aide and Picker (1996) reported that P deficiency reduced panicles, grain panicle, and filled grain panicle in rice. Compared with N nutrition, P nutrition of rice plants has received little attention, because under favorable soil conditions the response of rice to P fertilizer is far less marked than to N. Phosphorus deficiency is likely to develop in many soils under intensive rice cultivation, and the use of improved varieties in rice production will increase the problem (IRRI, 1993). If one of these two elements becomes limiting, N efficiency drops strongly (Marc, 2001). Phosphorus deficiency is common in all the soils, and must be corrected to obtain responses to other nutrients and to sustain rice soil productivity (Balasumbramanian *et al.*, 1995).

2.8 Fertilizer management in irrigated systems of Burkina Faso

Burkina Faso imports 95 percent of its fertilizer requirement from international traders and from bordering countries such as Mali and Côte d'Ivoire. The remaining five per cent is produced locally by the only fertilizer manufacturer in the country, the Industrial Company of Agricultural and Tradable Productions (CIPAM). In Burkina Faso, according to the study of AGRA (2010), 82% of the farmers are aware of the use of inorganic fertilizer. The level of practice is much lower than the level of awareness and the most practised ISFM techniques were crop rotation and compost (48%); use of farm yard manure (53%) and inorganic fertilizer (45%). The average use of mineral fertilizer is about 8 kg ha^{-1} (Bassole, 2007), which is similar to the average for SSA of 6.0 kg ha^{-1} (Wanzala-Mlobela m*et al.*, 2013). Fertilizers that are commonly used in irrigated systems in Burkina Faso are urea (46% N) and composite fertilizer NPK (mainly 14-23-14). The recommended rate of fertilizer in irrigated systems is 200 kg ha^{-1} of urea and 200 kg ha^{-1} of NPK. The current farmers' practices for N fertilizer application generally include basal broadcasting without incorporation before transplanting and/or one or two topdressings in the floodwater immediately after transplanting up to flowering (reproductive stage). The efficiency of fertilizer N use is generally low and this results not only in financial losses to farmers but also a detrimental impact on the environment. These conventional practices are largely based on common sense or convenience and are generally controlled by agroclimatic and socio economic factors. Numerous reports have demonstrated that these management practices for application of fertilizer N in transplanted rice are very inefficient (Pasandaran et *al*., 1999; Bowen et *al.*, 2004; Segda, 2006). Crop production systems that optimize yield, reduce N loss and improve N uptake are desirable. Rice soils in West Africa show marked responses to fertilizer N and judicious use of fertilizer N is a must. In order to meet ever-increasing demand for rice by a growing population, farmers will have to apply modest doses of N fertilizers to increase their yields and eventually the national production levels.

2.9 Summary of literature review and knowledge gaps

Nitrogen is the main nutrient limiting rice yield in irrigated rice systems and N fertilizer losses are very high in these cultivation systems. Ammonia can be lost by volatilization, leaching and denitrification. Many methods have been tested to reduce nitrogen loss from rice fields. In Burkina Faso, especially in the Sourou valley, the prevalent method of applying urea is by broadcasting and with this method farmers are losing about 65% of urea applied. Nitrogen use efficiency (NUE) is very low in this area.

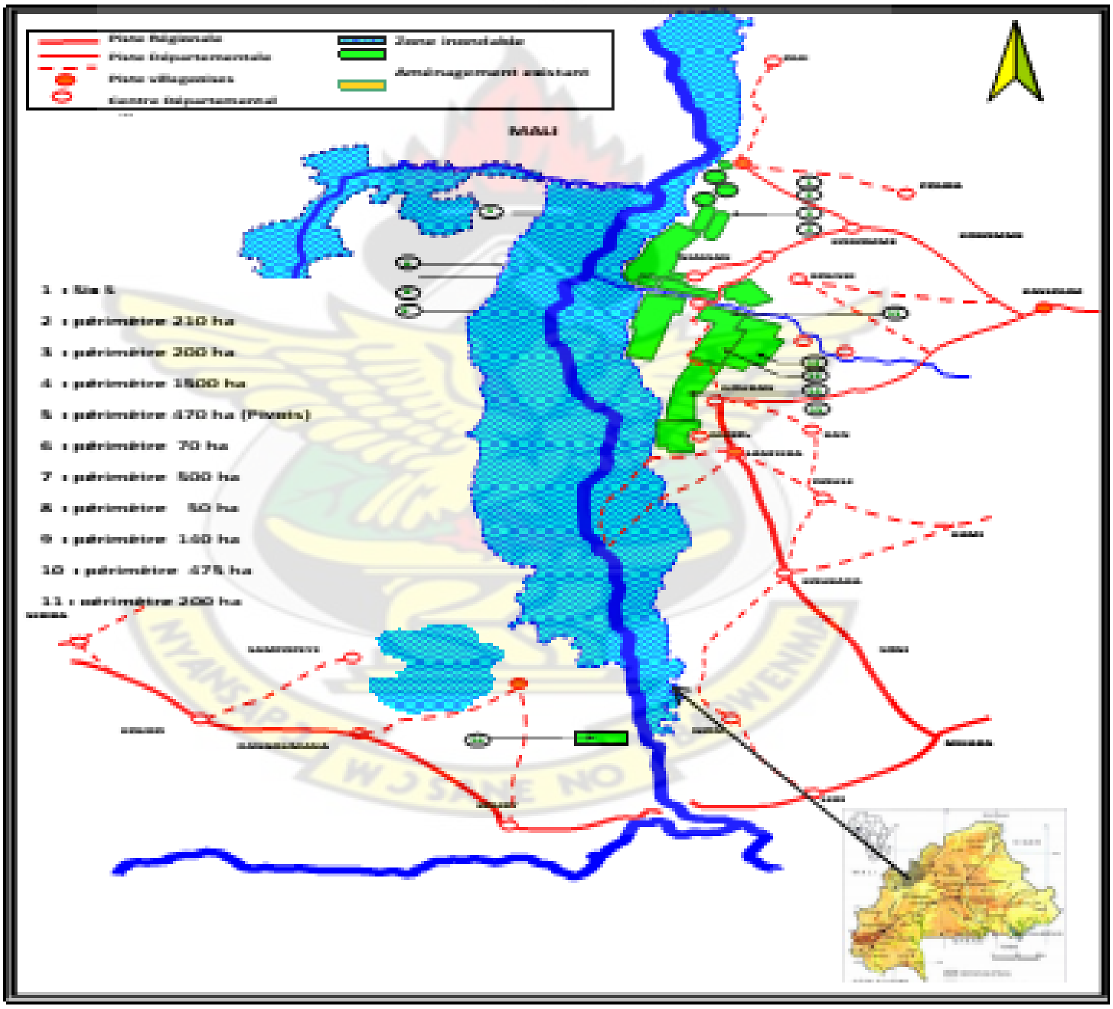
Deep placement of Urea supergranules that are compacted prilled urea is a promising technology that can be effectively used by farmers to increase their NUE and their yields. Deep placement of Urea supergranules is not well known by smallholder farmers. Little is known about the technology in Burkina Faso so, before its extension assessment of the suitability of the technology with rice varieties growing under flooded condition is necessary. Also, more informations have information have to be known about the efficient of the technology.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the experimental site

The study was carried out in the Sourou Valley during the wet season of 2012 and both dry season and wet season of 2013. The valley is an intensively cultivated area with a potential irrigated land of about 615, 000 ha (Figure 3.1). Irrigation water is supplied by Sourou River with a capacity of 600,000,000 m^3 (Dianou *et al.*, 2011). The site is located on 13 ° 00 'latitude north and 03 ° 20' longitude west.



Source: Rosillon and Bado-Sama (2006).

Figure 3.1: Area covered by Sourou valley

3.1.1 Climate

The region of Sourou is characterized by a north - Sudanian sahelian climate with an average rainfall below 900 mm. The rainy season is from June to October with high variability in time and space. Temperatures are stable and between a minimum of 17 °C in coolest season and maximum of 41 °C in hottest season. It is governed by two specific winds. The harmattan (Saharan anticyclone) brings dry air and dust from the Sahara desert and the second monsoon, which brings humid air from the Atlantic ocean (southwest). The average rainfall for the past ten years is 683.66 mm. The maximum rainfalls were 825.7 mm in 2012 and 745.3 mm in 2013.

3.1.2 Vegetation

The vegetation reflects the climatic and edaphic conditions as well as human interference. The region of Sourou is characterized by xerophyllous steppes with annual grasses such as *Aristida mutabilis*, *Cenchrus biflorus* and *Schoenefeldia gracilis*. This area is usually shrubby, dominated by thorn - bushes of the genera *Acacia* and *Balanites* (Fontes and Guinko, 1995).

In this zone, typical Sahelian species can be found such as *Acacia ehenbergiana*, *Aerva javanica*, *Andropogon gayanus* var. *tridentatus*. *Loudetia togoensis, Andropon ascinodis,* and *Pennisetum pedicellatum.* Trees species are dominated by *Mitragina Inermis, Acacia seyal, Balanites aegyptiaca, Anogneisus leiocarpus, Butyrospermum parkii, Lanéa microcarpa, Parkia biglobosa,* and *Piostigma sp*.

3.2 Soils of the study

The soils in Sourou Valley are mainly cambisols, poorly developed, hydromorphic soils and Vertisols (ISRIC, 2006) with fine texture, high water retention capacity, low permeability, poor ventilation of sub-surface horizons and strong compaction (Faggi and Mozzi, 2000; Fontes and Guinko, 1995).

3.3 Soil analysis

Before the beginning of all the trials, soil samples were taken for the analysis of total N, available P, total K and exchangeable K, pH in water, organic carbon and physical characteristics. Robinson pipette method was used for soil physical analysis (Delaune *et al*., 1991). The method is based on improved dispersion procedure. The soil sample was air dried and weighed. The sample was deflocculated by shaking in a dilute sodium oxalate solution. The colloid, clay and fine silt were separated from the sands by means of a 300 - mesh sieve. The clay and colloid were determined by sedimentation.

3.3.1 Determination of soil pH

The pH of the soil was determined using a pH meter with soil: water ratio of 1:2.5. A 20 g soil sample was weighed into a beaker. To this, 50 ml distilled water was added and the suspension was stirred continuously for 60 minutes and allowed to stand for 15 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the soil suspension.

3.3.2 Determination of soil organic carbon

A modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used in the determination of organic carbon. A 0.5 gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Two and half (2.5) milliliters of 1.0 *N* (0.1667 *M*) potassium dichromate solution were added to the sample and the blank. Concentrated sulphuric acid (5 ml) was carefully added to the soil from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (25 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 ml) was then added and titrated with 1.0 *M* ferrous sulphate ($FeSO_4$) solution.

Calculation:

$$\%\text{ organic C} = \frac{(\text{m.e.}K_2CrO_7 - \text{m.e.}FeSO_4)\times(1.32)\times 0.003}{\text{weight of soil}} \times 100$$

where:

m.e. = molarity of solution x ml of solution used

0.003 = m.e. wt of C in grams (12/4000)

1.32 = correction factor

3.3.3 Determination of available P

Available P was determined using the Bray P1 method (Olsen and Sommers, 1982). The method is based on the production of a blue complex of orthophosphate and molybdate in an acid solution. A 2.0 g soil sample was weighed into a 50 ml shaking bottle and 20 ml of Bray - 1 extracting solution was added. The sample was shaken for one minute and then filtered through Whatman filter paper grade N° 42. Ten millilitres (10 ml) of the filtrate was pipetted into a 25 ml volumetric flask and 1 ml each of molybdate reagent and reducing agent were added for colour development. The percent transmission was measured at 720 nm wavelength on a spectronic 21 D spectrophotometer. The concentration of P in the extract was determined by comparison of the results with a standard curve.

Calculation:

$$P(mg/kg) = \frac{Graph\,reading \times 20 \times 25}{w \times 10}$$

where:

20 = ml extracting solution

10 = ml initial sample solution

25 = ml final sample solution

w = sample weight in grams

3.3.4 Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986).

3.3.4.1 Exchangeable bases extraction

A 5 g soil sample was weighed into a leaching tube and leached with 100 ml buffered 1.0 *M* ammonium acetate solution at pH 7.

3.3.4.2 Determination of calcium and magnesium

To analyze for calcium and magnesium, a 25 ml aliquot of the extract was transferred into an Erlenmeyer flask. To this were added 1 ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 % potassium cyanide, 1 ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution. The solution was titrated with 0.01 *M* EDTA (ethylene diaminetetraacetic acid) to a pure turquoise blue color.

3.3.4.3 Determination of calcium

A 25 ml aliquot of the extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. Following this, were added 1 ml hydroxylamine, 1 ml of 2.0 % potassium cyanide and 1 ml of 2.0 % potassium ferrocyanide solution. After a few minutes, 5 ml of 8.0 *M* potassium hydroxide solution and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA solution to a pure blue color.

Calculation:

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$\text{Ca} + \text{Mg (or Ca) (cmol}_{+}\text{/kg soil)} = \frac{0.01 \times (\text{Va} - \text{Vb}) \times 1000}{\text{w}}$$

where:

w = weight (g) of air – dried soil used

Va = ml of 0.01 *M* EDTA used in sample titration

Vb = ml of 0.01 *M* EDTA used in blank titration

0.01 = concentration of EDTA

3.3.4.4 Determination of exchangeable potassium and sodium

Potassium (K) and sodium (Na) in the leachate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l K and Na solutions to 100 mg/l. In doing this, 25 ml portion of each solution was taken into 250 ml volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M* NH_4OAc solution was added to each flask and made to the volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5, 10 mg/l for K and Na. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively

Calculation:

$$\text{Exchangeable K } (\text{cmol}_+/\text{kg soil}) = \frac{(a-b) \times 250 \times \text{mcf}}{10 \times 39.1 \times w}$$

$$\text{Exchangeable Na } (\text{cmol}_+/\text{kg soil}) = \frac{(a-b) \text{ x } 250 \text{ x mcf}}{10 \text{ x } 23 \text{ x } w}$$

where:

a = mg K or Na/ l in the diluted sample percolate

b = mg/l K or Na in the diluted blank percolate

w = weight (g) of air - dried sample

mcf = moisture correcting factor

3.3.4.5 Calculation of cation exchange capacity (CEC)

The measurement of soil cation exchange capacity was determined by using a single extraction with 1.0 *M* silver thiourea (AgTU). A 2 g soil sample was weighed into an extraction bottle at 2 mm and 30 ml of 1.0 *M* Ag Tu solution was added. The bottle with its contents was shaken for 2 hours. The mixture was titrated with 0.01 *M* of AgTU solution.

3.4 Plant analysis

Plants were sampled from 1 m^2 in each subplot for yield component evaluation and a composite sample was made with each treatment with rice biomass and grain. Grain and biomass samples were brought to the laboratory for the analysis of total N, P and K.

3.4.1 Determination of total nitrogen, phosphorus and potassium in plants and soil

To determine the total nitrogen (N), phosphorus (P) and potassium (K), samples were first mineralized using H_2SO_4-Se-H_2O_2 (Houba *et al*., 1997). A 0.3 g of oven dried (70 °C) ground plant tissue or soil (0.25 mm, 60 mesh) was put into a labelled dry and clean digestion tube. Five (5) ml digestion mixture was added to each tube and the reagent blanks for each batch of samples. The samples were digested at 110 °C for 1 hour. The mixture was removed, cooled and three successive 1 ml portions of hydrogen peroxide were added. The temperature was raised to 330 °C to continue heating. About 25 ml of distilled water was added and mixed well until no more sediment dissolved. The digest was allowed to cool and made up to 50 ml with distilled water.

The total N and total P contents in the digest solution were assessed using an automatic colorimeter (Skalarsanplus Segmented flow analyzer, Model 4000-02). Total N was determined using a modified Bethelot reaction (Krom, 1980), and total P following the Murphy and Riley method (Murphy and Riley, 1962). Total K was determined using a flame photometer (Jencons PFP 7).

3.5 Experiments

3.5.1 Assessment of total nitrogen content with urea supergranule for rice growth in pot experiment

3.5.1.1 Experimental design

Pot experiment was carried out using a factorial design with the rice variety FKR62N. The first factor was the type of soil (acidic and alkaline) and the second factor was the type of urea fertilizer (prilled urea - PU and urea supergranules- USG at the same rate of 52 kg N $ha^{-1}$and the control). Each treatment was replicated 16 times for 4 sampling per treatment at different stages (tillering, panicle initiation, flowering and maturity) of rice growth. Plastic pots of 25 liters were filled with 10 kg of soil from Sourou valley. The soils were wetted during 4 days before transplanting and four plants of rice from thirty (30) days seedlings were transplanted into each pot. A recommended rate of phosphorus (69 kg of P_2O_5) and potassium (24 kg of K_2O ha^{-1}) were applied uniformly to all pots except the control at transplanting, as basal in the form of triple superphosphate and muriate of potash respectively. One granule of 1.8 g corresponding to 52 kg N ha^{-1} was placed seven days after transplanting (DAT) between four plants (Figure 3.2) in the pot receiving USG. The prilled urea at the same rate was split into two. The first half was applied 14 DAT and second half during panicle initiation. Irrigation of the pots was done when necessary.

Two types of soils were used for the pot experiment were slightly acidic and alkaline with low organic matter content and low total nitrogen. Soils used the study were cambisols and their initial chemical and physical characteristics are shown in the Table 3.1.

Figure 3. 2: Placement of urea in the pot.

Table 3.1: Initial soil chemical and physical characteristics.

Soil property	Acid soil	Alkaline soil
Clay (%)	37.70	19.61
Silt (%)	21.50	45.10
Sand (%)	40.80	35.29
Organic carbon (%)	1.53	1.33
Total N (%)	0.11	0.09
C/N	14.00	15.00
AvailP (mg/kg)	4.56	5.05
pH (1:2.5 H_2O)	6.30	8.02

3.5.1.2 Plant, soil and root sampling

Plant biomass was taken at tillering, panicle initiation, flowering and at maturity. At each stage, four (4) pots of each treatment were destroyed. Rice plants were removed and the roots were washed to remove the soil. Plant biomass and roots were then cut and air dried for two weeks. The samples from each pot were weighed before and after drying. The soil and plant samples were taken during the different stages of rice growth and analyzed for total N.

3.5.1.3 Plant total N, P and K calculation

Plant N, P and K contents were calculated by multiplying N, P and K concentrations by plant biomass weight at each stage.

3.5.1.4 Plant and soil analysis

Plant samples were brought to the laboratory for the analysis of total N, P and K as indicated in section 3.4. Before filling the pots, soil samples were analyzed for total N, available P, pH in water and organic C as described in section 3.3.

3.5.1.5 Growth parameters

The number of tillers were counted at the different stages to evaluate the effect of the type of urea fertilizer on tiller development.

3.5.2 Effect of deep placement of urea supergranule on nitrogen use efficiency

3.5.2.1 Experimental Design

Two varieties of rice (FKR 19 and FKR 62 N) were used for this experiment. Their characteristics are as shown in the Table 3.2.

Table 2.2: Rice varieties and their characteristics.

Varieties	Origin	Sowing-Panicle initiation (days)	Sowing-maturity (days)	1000 Grain weight (g)	Yield Potential (t/ha)
FKR 19	NIGERIA	85	120	25.3	5 - 6
FKR62N	SENEGAL	88	118	28.98	5 - 7

The experiment was laid in a split plot design. The first factor, variety was randomized on the main plot and the second factor, fertilizer was randomized on the sub - plot. The treatments comprising two improved rice varieties commonly grown by rice farmers in the Sourou irrigation scheme are FKR 19 and FKR 62 N. These rice varieties were combined with two types of urea fertilizer (prilled urea (PU) and urea supergranules (USG)) at the same rate of 52 kg N ha^{-1}and were replicated four times. The plot size was 20 m^2 (5m x 4m). The treatments were:

T_1= FKR 19 with no fertilizer;

T_2 = FKR 19 with prilled urea;

T_3 = FKR 19 with urea supergranule;

T_4 = FKR 62N with no fertilizer;

T_5 = FKR 62N with prilled urea;

T_6 = FKR 62N with urea supergranule.

3.5.2.2 Field preparation and planting of rice

A piece of land was selected for raising seedlings in one farmer's field. The land was puddled, cleaned and levelled. Then the sprouted seeds of the two varieties of rice were sown in prepared nurseries one month before the beginning of the experiment. Proper care was taken to protect the seeds and seedlings in the nursery bed. Farmers' fields were also prepared by ploughing and then levelled with wooden plank. Thirty (30) day-seedlings were transplanted at a spacing of 20 cm x 20 cm. Each plot had independent drainage and irrigation ditches, so as to prevent the spread of water and fertilizers between plots. Irrigation was applied when necessary to both PU and USG-plots throughout the cropping seasons. Prilled urea ($CO(NH_2)_2$) containing 46% N was used for N supply. Urea supergranules (USG) which is urea compacted at different sizes (1.8 g corresponding to 113 kg ha^{-1} of urea) was used for fertilizer deep placement. The USG granule was placed at a depth at of 5 - 7 cm into the soil between four (4) hills (Figure 3.3). Prilled urea was split into two and was applied at

14 days after transplanting and at panicle initiation. The USG granule was applied only once at 7 days after transplanting. Triple superphosphate (TSP) containing 46% P_2O_5 was used to provide P and muriate of potash (KCl) containing 60% K_2O was used to provide potassium. Recommended basal rates of P (69 kg of P_2O_5) and potassium (24 kg of K_2O ha^{-1}) were applied uniformly to all the plots except the control at transplanting (Table: 3.3). The soils (vertisols and cambisols) used for the experiment were slightly acidic with low organic carbon and low total N contents. The soils were predominantly sandy-clay and their characteristics are presented in Table 3.4.

Figure 3.3: Application of urea supergranule.

Table 3.3: Fertilizer rates.

Fertilizer type	Fertilizer rate		
	rate kg ha^{-1}	rate kg ha^{-1}	g 20 m^{-2}
KCl (60% K_2O)	24 K_2O	40 KCl	80 KCl
TSP (46% P_2O_5)	69 P_2O_5	149 TSP	298 TSP

Table 3.4: Soil chemical and physical properties at the experimental site before planting.

Soil property	Dry-wet 2013	Wet 2012
Clay (%)	44.7	36.8
Silt (%)	22.3	21.8
Sand (%)	33.0	41.4
Organic carbon (%)	1.6	0.7
Total N (%)	0.1	0.06
C/N	14.0	11.0
Available P (mg/kg)	5.6	4.6
pH (1:2.5 H_2O)	6.2	6.1
CEC ($cmol_+$/kg)	8.7	8.6
Exch Na^+ ($cmol_+$/kg)	0.2	0.2
Exch K^+($cmol_+$/kg)	0.5	0.3
Exch Ca^{2+}($cmol_+$/kg)	4.9	5.5
Exch Mg^{2+}($cmol_+$/kg)	1.2	0.8

3.5.2.3 Plant sampling

After harvest, grain and straw samples were collected from each treatment and analyzed for their total N, P and K contents. The assessment of yield components was made on $1m^2$ in each plot. The number of tillers and the number of panicles per

m^2 were collected. Biomass and grain samples were collected from each plot and a sub sample collected for each treatment for the determination of total N, P and K.

3.5.2.4 Soil sampling and analysis

Soil samples were collected from five points in each plot at 0 – 20 and 20 - 40 cm depths. The samples were carefully mixed to provide composite sub - sample for the analysis of total N, available P, organic C and pH in water.

3.5.2.5 Assessment of nitrogen use efficiency

The following parameters were calculated to assess N use efficiency: The Agronomic Efficiency, which is an indicator of the ability of plant to increase grain yield in response to urea application and reflects the overall efficiency of the N used for dry matter production.

Agronomic N use Efficiency (AE) was determined using the equation (Craswell and Godwin, 1984):

$$AE = \frac{(GYN - GYO)}{Nr}$$

The Recovery Efficiency of N (RE) is the increase in N uptake per kg of N applied and was calculated using the equation (Cassman *et al.*, 1996):

$$\%RE = \frac{(UN - UO)}{Nr} * 100$$

It was the primary index to describe the characteristics of N uptake and utilization in rice. Physiological efficiency (PE) represents the ability of a plant to transform a given amount of acquired nutrient into economic yield or plant dry matter and was calculated using the equation:

$$PE = \frac{(\mathrm{GYN} - \mathrm{GY0})}{(\mathrm{UN} - \mathrm{U0})}$$

where:

Nr is the amount of N fertilizer applied (kg N ha^{-1});

GY is grain yield, SY is straw yield;

GYN is the dry grain yield with applied N fertilizer;

GYO is the dry grain yield without N fertilizer applied;

UN is the plant N accumulation with applied N fertilizer (kg N ha^{-1});

U0 is the plant N accumulation without N fertilizer applied (kg N ha^{-1}).

3.5.3 Evaluation of pH and ammonium concentration of floodwater

The experiment on the effect of fertilizer deep placement with urea supergranule on nitrogen use efficiency was used to evaluate floodwater pH and ammonium during ten days.

3.5.3.1 Floodwater sampling and pH measurement

Before sampling, floodwater pH was taken during 10 days after prilled and supergranules urea application. Half rate of PU was applied and full rate of USG was applied. A pH - meter was used to read directly the value of pH in each plot. Floodwater samples were taken before and after urea application during ten (10) days. Plastic bottles of 150 ml were used to sample floodwater. The samples were kept in the refrigerator until analysis of ammonium (NH_4^+) concentration in the floodwater.

3.5.3.2 Floodwater analysis

Floodwater NH_4^+ concentration was determined in the laboratory by the colorimetric method. The colorimetric method for NH_4^+ quantification was the phenol-hypochloride method. Ammonium ion reacts with hypochlorous acid and salicylate ions in the presence of nitroferricyanide to form the salicylic acid analog of indophenolblue.

3.5.4 Evaluation of nitrogen use efficiency with different levels of phosphorus

3.5.4.1 Experimental design

A split plot with an absolute control was used as the experimental design for this experiment. The first factor, N form was randomized on the main plot and the second factor, P was randomized on the sub - plot. Two sizes of urea supergranules (1.8 and 2.7g corresponding to 52 kg N ha^{-1}) were combined with 5 levels of P (0, 20, 30, 40 and 40 kg P ha^{-1}) to assess the effect of phosphorus with the two sizes of urea supergranules on N use effeciency. One variety of rice (FKR 62N) was used in this experiment. In total, there were 11 treatments with four (4) replications on the elementary plot of 20 m^2. The treatments and their fertilizer rates are shown in Tables 3.5 and 3.6.

Thirty (30) day old seedlings were transplanted at a spacing of 20 cm x 20 cm. Each plot had independent drainage and irrigation ditches, so as to prevent the spread of water and fertilizers between adjacent plots. The USG granular was placed deeply in soil at 5 - 7 cm between four (4) hills. Prilled urea was split in two and was applied at 14 days after transplanting and at panicle initiation. The USG granular was applied only once at 7 days after transplanting. Irrigation was applied when necessary throughout the cropping seasons.

Table 3.5: Treatments and fertilizer rates.

Treatments	Rate of fertilizer in g 20 m^{-2}		
	P_2O_5	K_2O	Urea (g)
Control	0	0	0
G1 × P_0	0	24	1.8 /4 hills
G1 × P_{20}	46	24	1.8 /4 hills
G1 × P_{30}	69	24	1.8 /4 hills)
G1 × P_{40}	92	24	1.8 /4 hills
G1 × P_{50}	115	24	1.8 /4 hills
G2 × P_0	0	24	0
G2 × P_{20}	46	24	2.7 /4 hills
G2 × P_{30}	69	24	2.7 /4 hills
G2 × P_{40}	92	24	2.7 /4 hills
G2 × P_{50}	115	24	2.7 /4 hills

G1= USG1.8 g (corresponding to 52 kg N/ha at the spacing of 20 x 20 cm)

G2= USG 2.7 g (corresponding to 80 kg N/ha at the spacing of 20 x 20 cm)

Table 3.6: Fertilizers and their rates.

Fertilizer	Fertilizer rate		
	Rate kg ha^{-1}	Rate kg ha^{-1}	g/ 20 m^{-2}
KCl (60% K_2O)	24 K_2O	40 KCl	80 KCl
TSP (46% P_2O_5)	46 P_2O_5	99 TSP	198 TSP
	69 P_2O_5	149 TSP	298 TSP
	92 P_2O_5	198 TSP	396 TSP
	115 P_2O_5	248 TSP	496 TSP

Soil used for the experiment was neutral and predominantly sandy clay. Soil showed very low contents in organic carbon, total nitrogen and low available phosphorus (Table 3.7).

Table 3.7: Soil chemical and physical characteristics before trial establishment.

Soil property	Value	
	0 – 20 cm	20 – 40 cm
Clay (%)	41.18	49.62
Silt (%)	23.53	17.65
Sand (%)	35.29	33.33
Organic carbon (%)	0.93	0.45
Total N (%)	0.07	0.04
C/N	13.00	11.00
pH($_{1:2.5}$ H_2O)	7.18	7.32
Avail P (mg/kg)	1.30	3.69

3.5.4.2 Plant sampling and chemical analysis

After harvest, grain and straw samples were collected from each treatment plot to analyze for their total N, P and K contents. The assessment of yield components was made on 1m^2 in each plot. Plant samples were oven dried at 65 °C for 48 hours, ground and sieved through a 0.2 mm mesh for the total N, P and K analysis.

3.5.4.3 Soil sampling and chemical analysis

Soil samples were sampled from five points in each plot at 0 - 20 cm and 20 - 40 cm depths. The samples were carefully mixed after which composite sub – samples were taken for the analysis of total N, available P, organic C and pH in water.

3.6 Statistical and data analysis

Data analyses were conducted on individual year data. The analysis of variance was conducted in accordance with the different designs using Genstat package edition 9th to determine the significance of the effects of N fertilization, cropping varieties, seasons and their interactions on yields. Treatment means were compared with the least significant different (Lsd) at the probability 0.05. Graphical presentations were done using Excel software. Linear regression analysis was used to establish the relationship among grain yield, grain nutrient uptake and nitrogen use efficiency.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results of the pot experiment

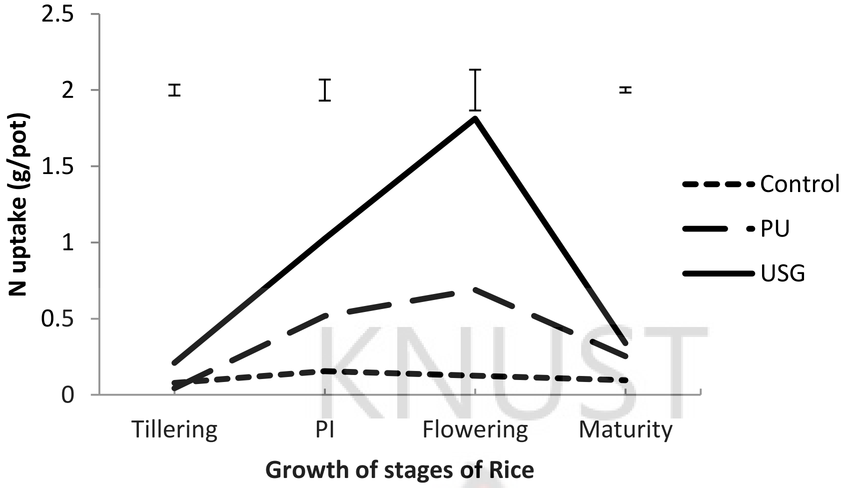
4.1.1 Nitrogen uptake at different rice growth stages

Nitrogen patterns at different stages of rice growth are presented in Figure 4.1. During rice growth N uptake increased until flowering and then decreased towards maturity with USG and PU treatments. Nitrogen uptake was higher when rice was treated with USG than PU and the control. The peak values at flowering with USG and PU were 1.813 and 0.689 g pot^{-1}, respectively. Nitrogen uptake with the control was stable throughout the growing period. The lowest N uptake was recorded with the control.

Significant differences ($P < 0.05$) were observed in N uptake with the two type of soil (Appendix 1). Nitrogen uptake patterns were similar in acid and alkaline soils. During rice growth stages, plant N uptake increased and a peaked at flowering stage in both soils (Figure 4.2). After this stage, plant N uptake decreased in both soils until rice maturity. Plant N uptake was also significantly greater in the acid soils at rice tillering, panicle initiation and at flowering stages than in the alkaline soils.

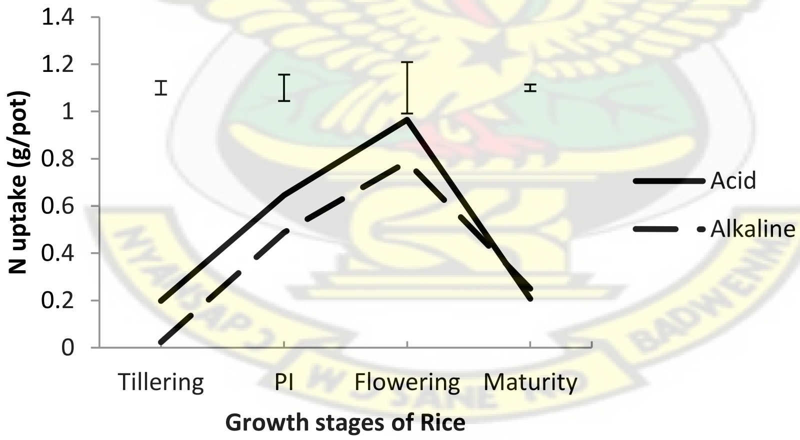
Significant ($P < 0.05$) interactive effects were observed among soil type, type of urea fertilizer and rice growth stages (Figure 4.3 and Appendix 1). Nitrogen uptake was high in the two types of soil with the use of USG during all the growth stages of rice and the maximum uptake was observed at flowering in the two types of soils. The increases in N uptake using USG from the acid and the alkaline soils at flowering stage over PU were 135 and 206 %, respectively. The acid soil increased N uptake by

19% using USG. The lowest uptake was recorded with PU (0.04 g/pot) in the acid soil and the control (0.01 g pot^{-1}) in the alkaline soil at tillering stage.



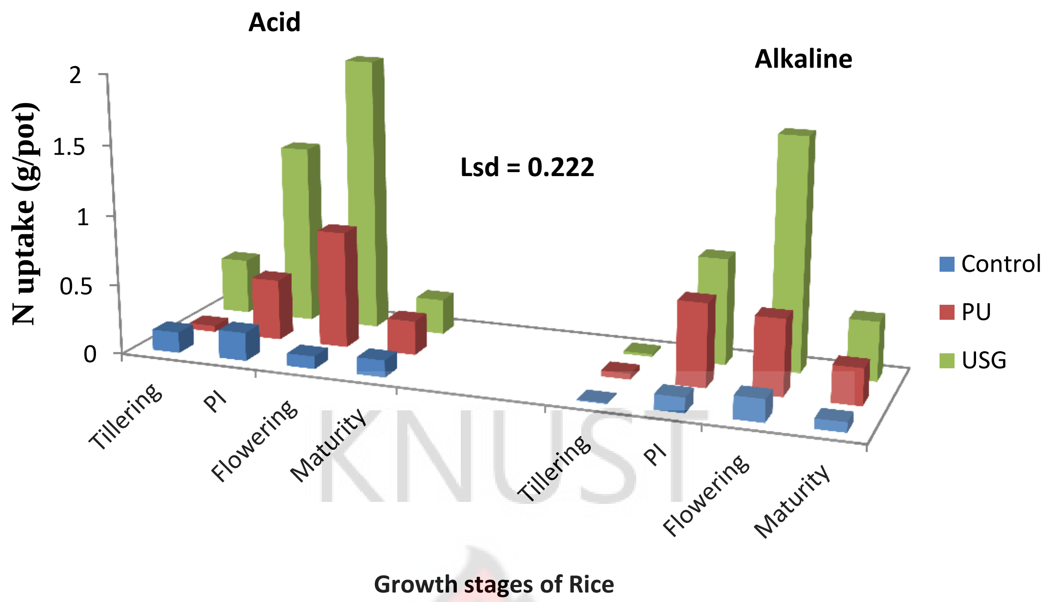
PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.1: Nitrogen uptake at different rice growth stages as affected by type of urea fertilizers.



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.2: Nitrogen uptake at different rice growth stages from acid and alkaline soils.



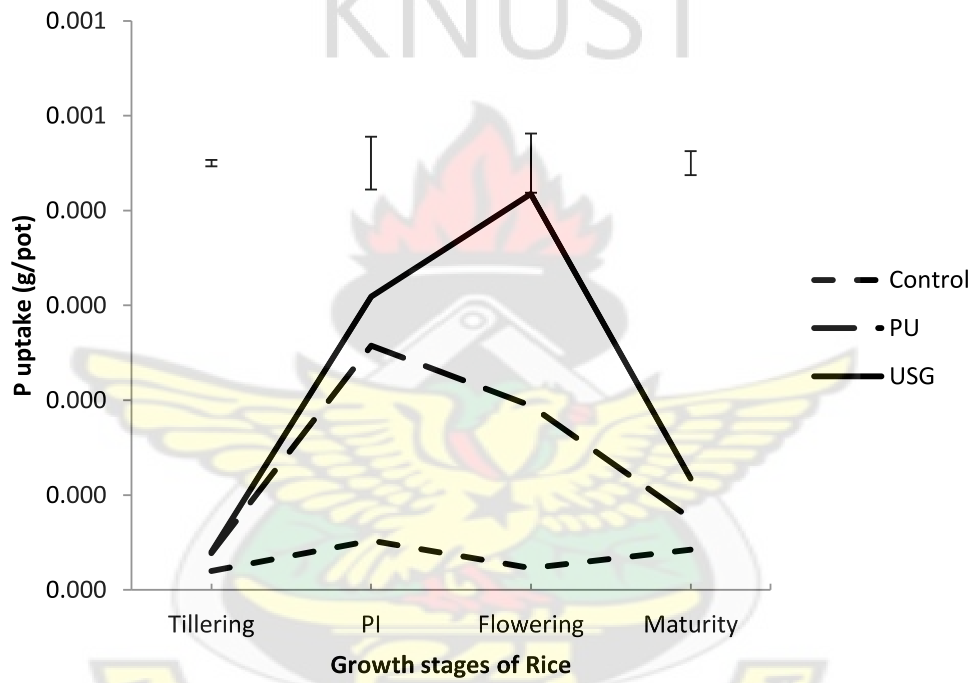
PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.3: Nitrogen uptake at different rice growth stages as affected by soil and urea fertilizers types.

4.1.2 Phosphorus uptake at different rice growth stages

Phosphorus uptake patterns of rice plant with the different types of urea fertilizer are shown in Figure 4.4. The use of USG increased P uptake of rice sharply from tillering to flowering where it attained a peak of 0.418 g pot^{-1} and then declined. A similar pattern was obtained in P uptake with PU treatment which rose up until panicle initiation with a peak value of 0.257g pot^{-1} and then declined until rice maturity. Lowest P uptake was observed with the control which fluctuated during rice growth stages.

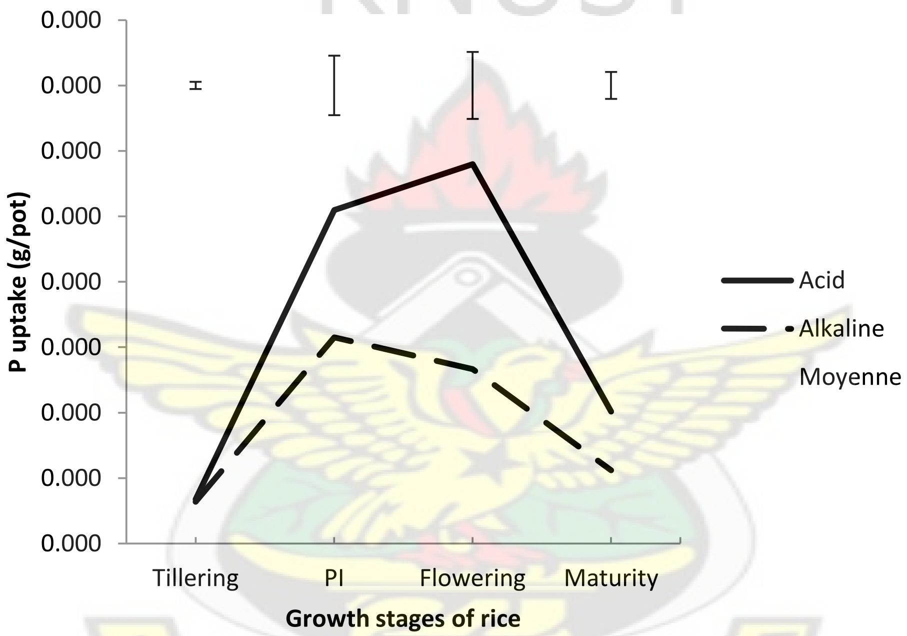
Soil type significantly (P <0.05) affected P uptake (Appendix 2). The highest (0.303 g/ pot^{-1}) and the lowest (0.021 g/ pot^{-1}) P uptake were recorded on the acid and the alkaline soils, respectively (Figure 4.5). Rapid P uptake was observed after rice tillering until panicle initiation and at flowering in the alkaline soil and the acid soil, respectively. After these growth stages rapid decline was observed in P uptake in both soils until rice maturity.



PI = Panicle Initiation. Bars indicate Lsd (5%).

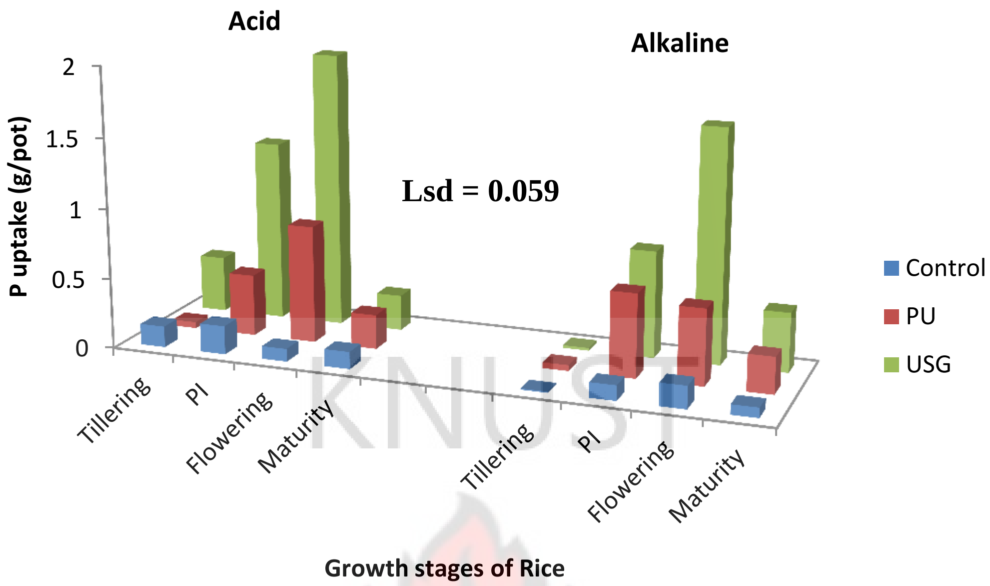
Figure 4.4: Phosphorus uptake at different rice growth stages as affected by type of urea fertilizers.

Figure 4.6 shows the interactive effects among the soil type, the type of urea fertilizer and rice growth stages on rice P uptake. Significant effects (P <0.05) were observed with P uptake (Appendix 2). The maximum P uptake was recorded at flowering stage with the two types of soils with the use of USG. The increases in N uptake in the acid and the alkaline soils at this stage over PU were 135% and 207%, respectively. The best N uptake was observed in acid soil (1.97 g pot^{-1}) that increased N uptake by 19% over alkaline soil. Low P uptake was observed with the control in the two types of soils during rice growth stages generally. High P uptake was observed in the acid soil compared to the alkaline soil.



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.5: Phosphorus uptake at different rice growth stages from acid and alkaline soils.



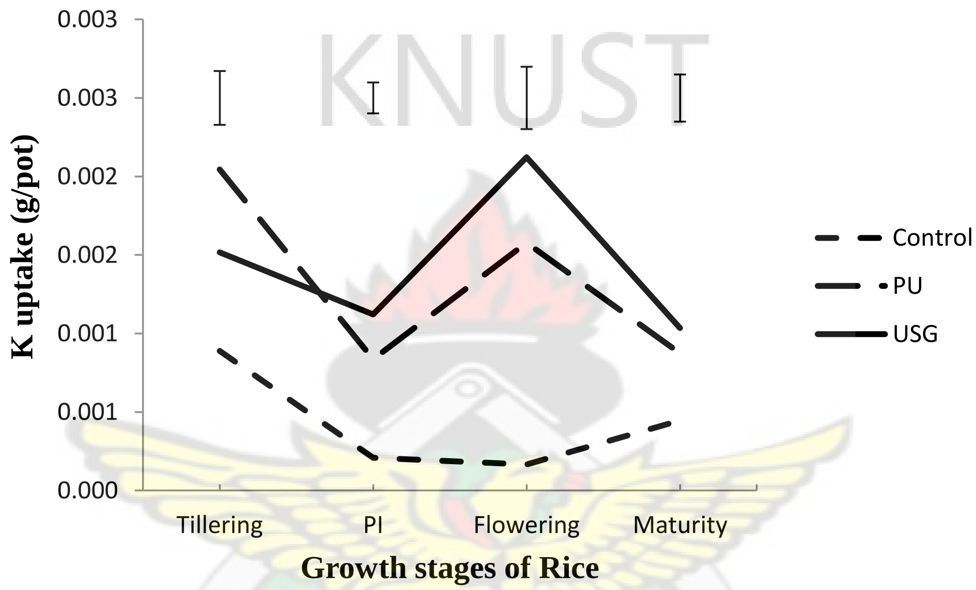
PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.6: P uptake at different rice growth stages as affected by soil and urea fertilizers types.

4.1.3 Potassium uptake at different rice growth stages

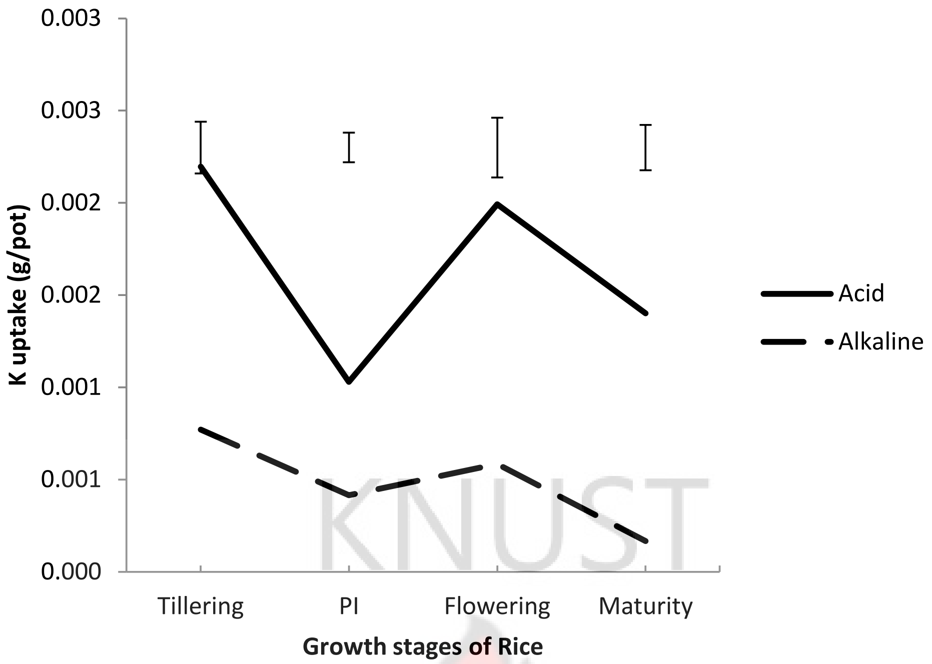
Similar K uptake patterns were observed with the use of PU and USG at the different stages of rice growth except before the PI growth stage (Figure 4.7). Significant difference ($P < 0.05$) was observed in K uptake with the treatments (Appendix 3). Potassium uptake decreased after tillering until panicle initiation. At this stage K uptake rose up at flowering and declined until rice maturity in both soils. The highest K uptake was observed at flowering (2.123 g pot^{-1}) and at tillering (2.045 g pot^{-1}) with USG and PU, respectively. Potassium uptake with the control declined after tillering stage and remained stable at panicle initiation and flowering. An increased was observed at rice maturity in K uptake with the control.

Potassium uptake in the two types of soils followed the same patterns as nitrogen uptake (Figure 4.8). Potassium uptake was significantly (P< 0.05) (Appendix 3) higher during rice growth in acid than alkaline soil.



PI = Panicle Initiation. Bars indicate Lsd (5%).

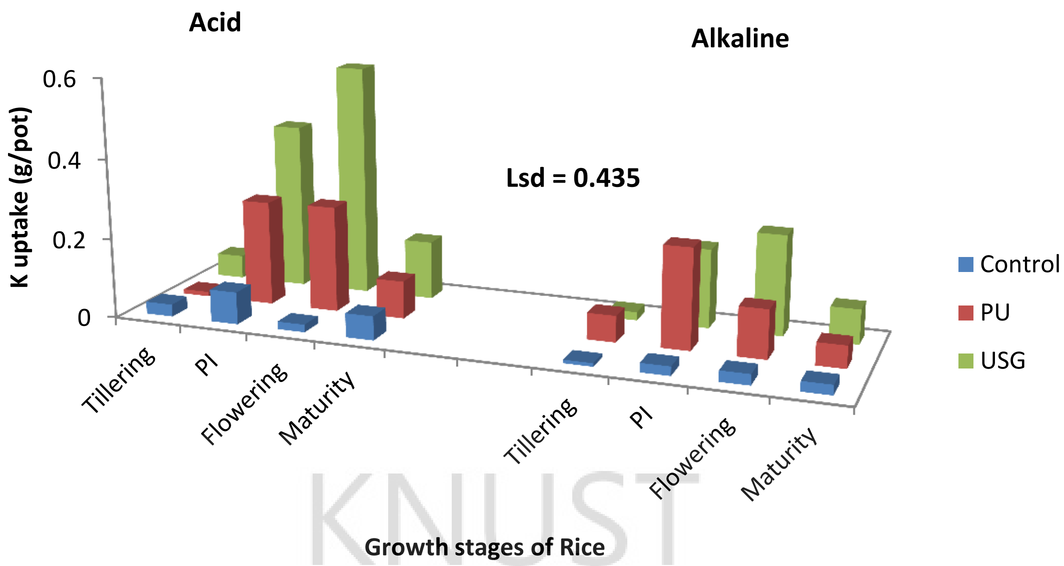
Figure 4.7: Potassium uptake at different rice growth as affected by the type of urea fertilizers.



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.8: Potassium uptake at different rice growth stages from acid and alkaline soils

Potassium uptake was significantly (P <0.05) affected by the soil type, urea fertilizer type and rice growth stages (Appendix 3). Higher K uptake was recorded at flowering stage in the two types of soil with the use of USG (Figure 4.9). The highest K uptake (0.58 g pot^{-1}) was observed in the acid soil and the increase over USG in alkaline soil was 132% at flowering stage. The use of USG also increased K uptake by 119 and 106% compared to PU in the acid and the alkaline soils, respectively. The lowest K uptake was observed at tillering stage with PU treatment (0.03 g pot^{-1}) and the control (0.01 g pot^{-1}) in the acid and the alkaline soils respectively. Potassium uptake was high in the acid soil compared to the alkaline soil during all the growth stages, generally (Figure 4.9).



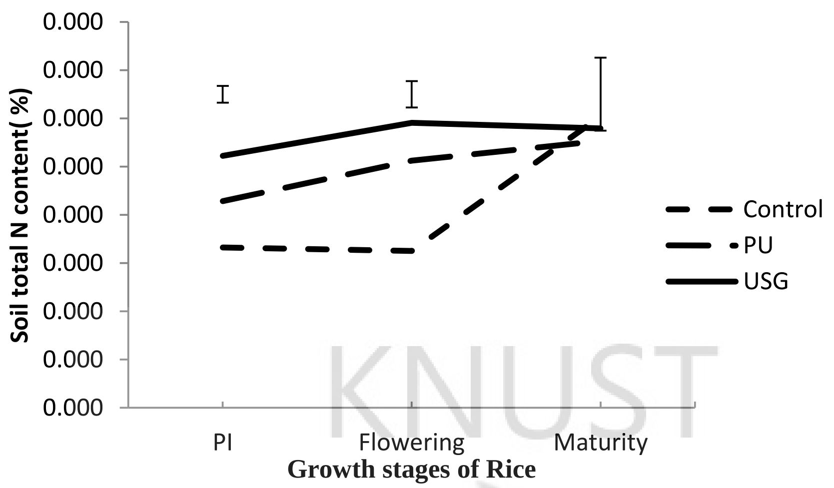
PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.9: Potassium uptake at different rice growth stages as affected by soil and urea fertilizers types.

4.1.4 Soil total nitrogen as affected by urea fertilizers and two soil types

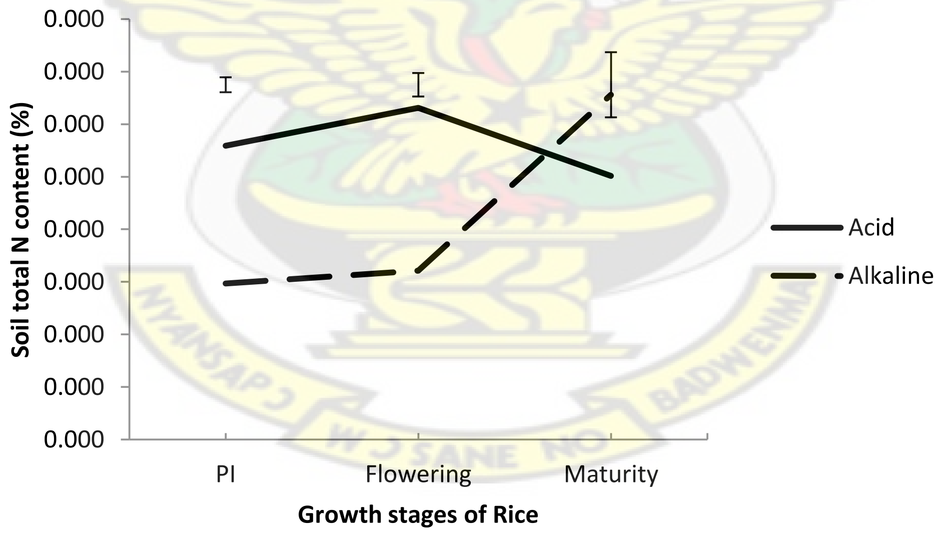
Nitrogen fertilizer significantly ($P < 0.05$) (Appendix 6) affected soil total N. Soil total N increased until maturity with the use of urea fertilizer. Soil total N of the control increased quickly from flowering stage to maturity (Figure 4.10). The highest N contents were recorded with the USG treatment.

Figure 4.11 shows the patterns of soil N in the acid and the alkaline soils. Significant difference ($P < 0.05$) was observed between both soils. Whereas N content in the acid soil tended to increase until flowering, N content in the alkaline soil tended to stabilize at this stage but remained below N curve with acid soil. After the flowering stage, N content in acid soil decreased but N content in alkaline soil increased until maturity.



PI = Panicle Initiation. Bars indicate Lsd (5%).

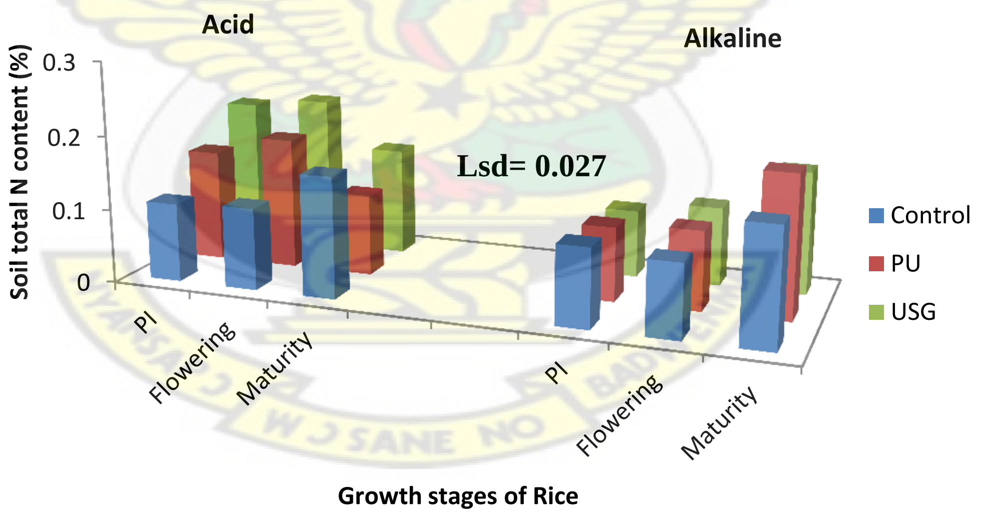
Figure 4.10: Soil total N content at different rice growth stages as affected by type of urea fertilizers.



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.11: Soil total N content at different rice growth stages in acid and alkaline soils.

Interactive effects (P <0.05) were observed among soil type, type of urea and rice growth stages on soil total N content (Appendix 6). Soil N tended to be stable during PI and flowering stage and increased at maturity with all the treatments in the alkaline soil. The same trend was observed with the control in the acid soil. The highest and the lowest values of soil total N contents in the acid soil were recorded at flowering stage (0.21 g pot^{-1}) with the use of USG and at PI (0.11 g pot^{-1}) with the control respectively (Figure 4.12). In the alkaline soil, the highest and lowest soil total N contents were observed with the use of PU (0.19 g pot^{-1}) at maturity and the control at flowering (0.1 g pot^{-1}). The use of USG increased soil total N content by 18% over PU in the acid soil at flowering stage. In the alkaline soil, the use of PU increased soil total N content by 17% over USG at maturity.



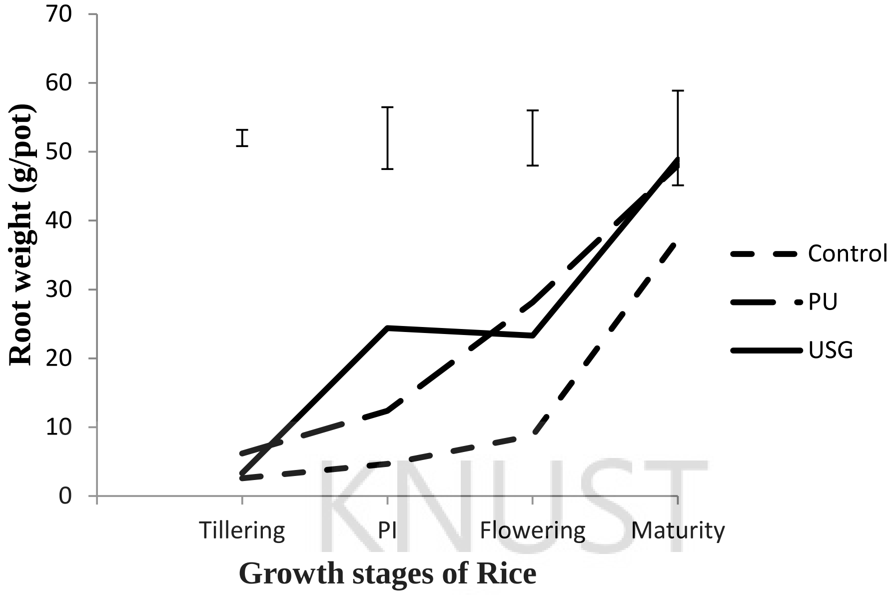
PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.12: Soil N content at different rice growth stages as affected by soil and urea fertilizers types.

4.1.5 Root development as affected by urea fertilizers on two soil types

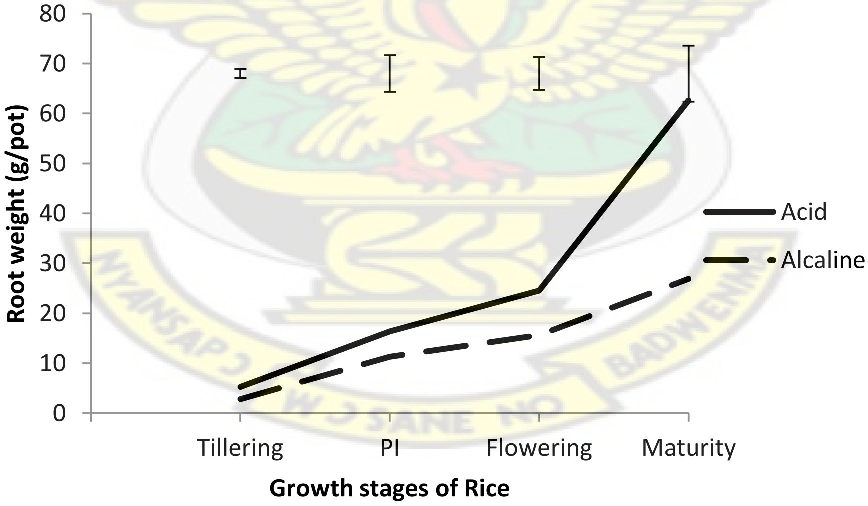
Figure 4.13 shows the patterns of root growth at different stages of rice growth with all the treatments. Significant differences ($P<0.05$) were observed among the treatments. Root development with the control and USG tended to increase during rice growth period. Root weights also increased with PU and remained stable between panicle initiation and flowering. After this period, an increase was observed until rice maturity. The lowest root weight was recorded with the control. Root weight with USG treatment was higher than root weights with PU during tillering until panicle initiation and then tended to be similar at the end of the experiment.

The acid soil significantly ($P <0.05$) (Appendix 4) increased root weight compared to the alkaline soil during rice growth stages (Figure 4.14). The increases in root weight in the acid soil were 89, 45, 57 and 132% greater at tillering, panicle initiation, flowering and maturity than in the alkaline soil at these stages, respectively.



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.13: Root development at different rice growth stages as affected by type of urea fertilizers.

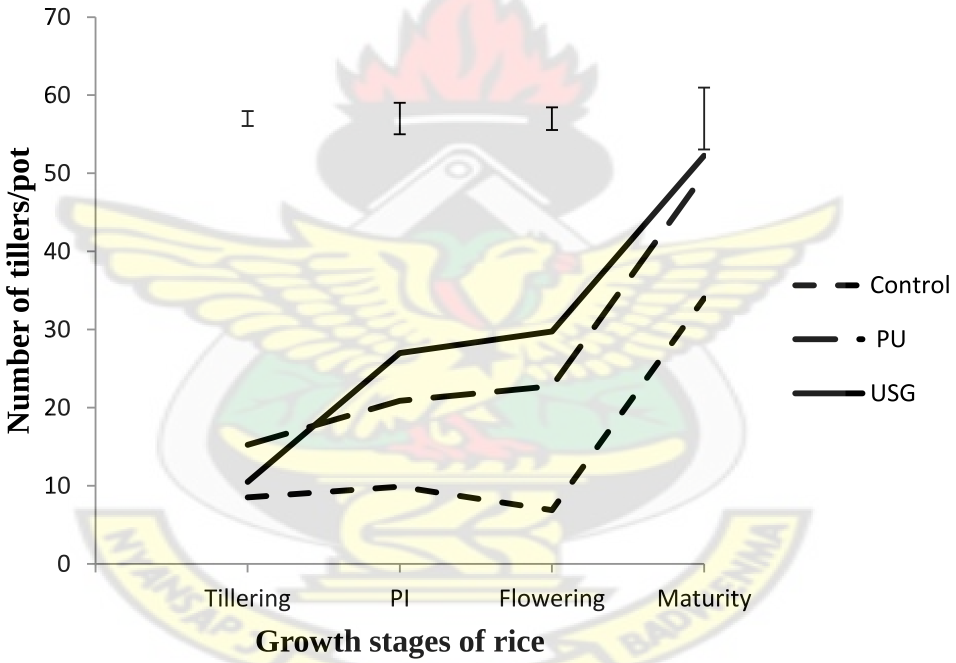


PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.14: Root development at different rice growth stages in acid and alkaline soils.

4.1.6 Tiller development with urea fertilizers on two soil types

Figure 4.15 shows the patterns of the number of tillers with the different treatments during rice growth. The lowest number of tillers was observed with the control during the different growth periods. The number of tillers with the control was stable at the beginning with a decrease observed at flowering. After this period, the tiller number rose up until maturity. Similar patterns were observed with PU and USG with the number of tillers increasing until maturity. The number of tillers was higher with USG treatment. Significant difference (P 0<0.05) (Appendix 5) was observed between PU and USG at panicle initiation and flowering stages.



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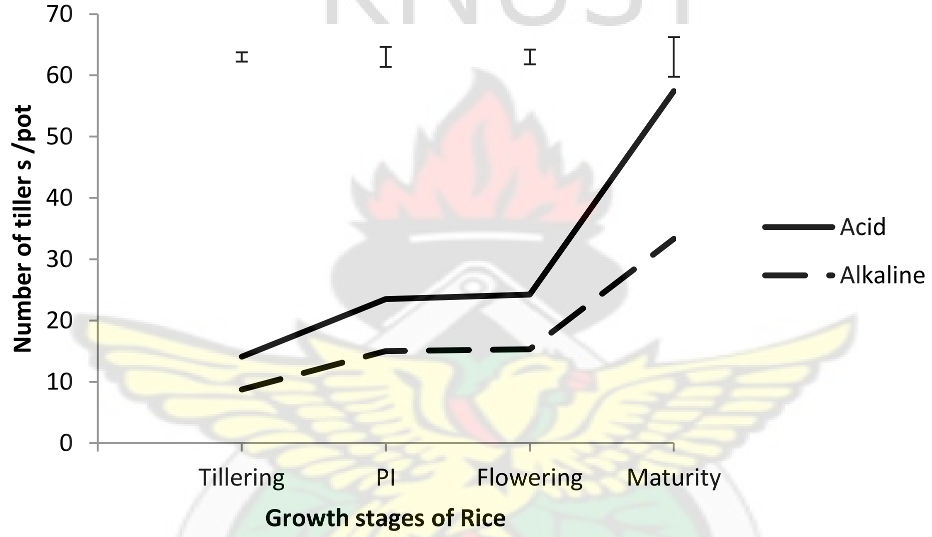
PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.15: Number of tillers at different rice growth stages as affected by type of urea fertilizer.

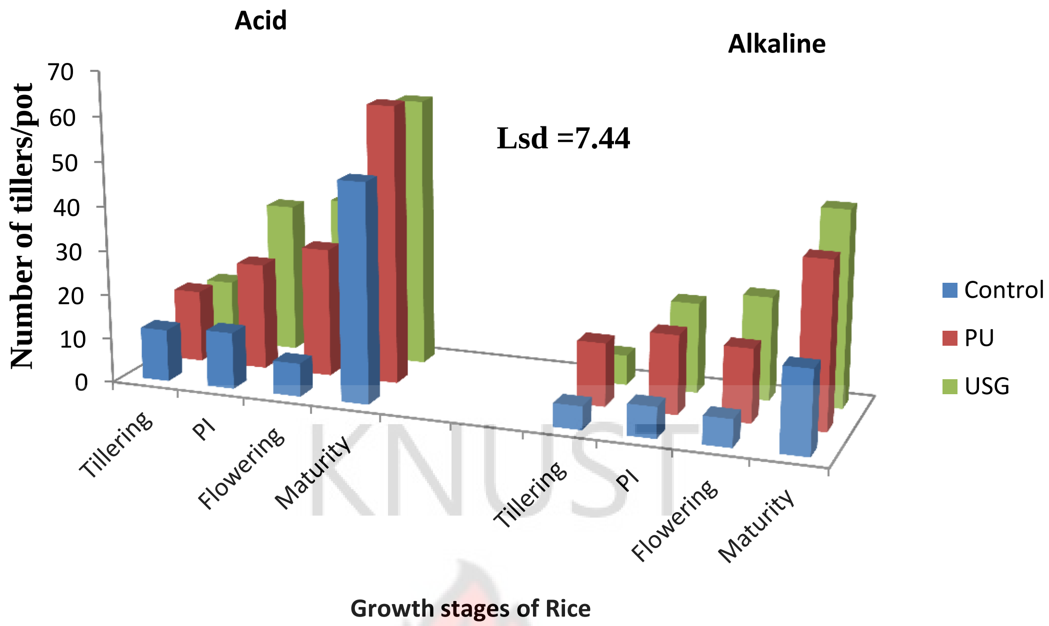
Figure 4.16 shows that the number of tillers significantly (P <0.05) increased (Appendix 5) in the acid soil than the alkaline soil during rice growth period and with all the treatments. The highest number of tillers was recorded in the acid soil with PU treatment (63 tillers/pot) followed by USG treatment (61 tillers/pot). The results showed that the acid soil increased the number of tillers by 67% over the alkaline soil generally.



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.16: Tiller formation at different rice growth stages in acid and alkaline soils.

Significant difference (P <0.05) was observed with the number of tillers among urea fertilizer type, soil type and rice growth stages (Appendix 5). The number of tillers increased until maturity with the two types of soil generally. The highest numbers of tillers were recorded in the acid soil. The use of USG produced greater number of tillers compared to the use of PU in both the acid and alkaline soils (Figure 4.17).



PI = Panicle Initiation. Bars indicate Lsd (5%).

Figure 4.17: Number of tillers developed at different rice growth stages as affected by soil and type of urea fertilizer.

4.2 Discussion

4.2.1 Effect of soil and urea fertilizer types on N, P and K uptake

The amount of total N, P and K increased in rice plant with the urea deep placement (UDP) during the study. The results are in agreement with findings of Bowen *et al.* (2004) and Pasandaran *et al*. (1999), who reported that urea deep placement technology was highly effective in improving crop uptake of applied N fertilizers in irrigated rice system in Asia. The results can be attributed to the decrease of soil N loss with USG deep placement observed in pot experiment. According to the study of

De Datta (1986), the use of urea supergranules could synchronise N release with plant requirements and provide sufficient N in a single application to satisfy plants' requirements while maintaining mineral N in the soil throughout the growing season. The increase in P and K uptake with USG can also be explained by the interdependence between N, P and K as reported by Rabat (2003). It is known that N is a limiting factor in irrigated rice systems (Segda, 2006); its availability also increases phosphorus and potassium uptake. The increase can also be attributed to the root development induced by USG deep placement. This finding is in agreement with the findings of Savant and Stangel (1990) who reported that rice roots tend to proliferate near the placement point of urea supergranule and to increase during many weeks after urea placement.

Soil type also affected N, P and K uptake. Nutrient uptake was higher in the acid soil and this can be explained by the fact that pH increase inhibits root proliferation as reported by Shaaban *et al.* (2013). The lower density of roots in the alkaline soil could affect the uptake of nutrients. The rise in pH increased the rate of ammonium conversion to ammonia, which increased its volatilization. Deep placement of urea supergranules has been shown to effectively reduce N loss and increase rice yield on near neutral pH soils with alkaline floodwater (Singh, 2005 and Cai *et al.*, 2002).

4.2.2 Effect of urea fertilizer and soil types on soil total nitrogen

Nitrogen availability varied with soil pH during the study. Soil N was higher in the acid soil compared to the alkaline soil during the panicle and flowering stages. This result can be explained by the fact that nitrogen loss may be high in the alkaline soil due to high soil pH. Ammonia losses from floodwater may reduce soil nitrogen availability. In fact, the conversion of NH_4^+ to NH_3 is governed by soil pH. During urea hydrolysis the pH surrounding the granule initially rises (pH > 8) as ammonium bicarbonate is formed. Longo and Melo (2005) measured the rate of urea hydrolysis under laboratory conditions using a range of soil pH from 2.2 to 8.0. According to their finding, as the soil pH increased the rate of urea hydrolysis increased almost exponentially. They also found that the highest rate of urea hydrolysis was at pH 8.0. Similar results were reported by Vlek and Craswell (1981) and Fillery *et al.* (1986). At rice maturity, soil N declined in the acid soil and increased in the alkaline soil. The use of USG increased soil total N more than PU urea. This can be attributed to the fact that USG can be considered slowly available N fertilizer that provides N to meet plant requirements (Savant and Stangel, 1990).

The type of urea fertilizer significantly affected soil total nitrogen. Higher nitrogen content was recorded by urea deep placement with USG throughout the experiment. This result can be attributed to the incorporation of nitrogen that reduced N losses via volatilization and denitrification and optimized nitrogen availability in soil (Choudhury *et al.*, 1997; De Datta, 1981).

4.2.3 Effect of urea fertilizer and soil types on rice root growth and tiller development

Deep placement of urea with USG resulted in greater rice root development compared to prilled urea. Similar results were reported by Savant and Stangel (1990). The increase in root weight can be attributed to the ammoniacal N which, improved root dry weight in crop plants. Incorporation of the urea to soil placed N into the anaerobic soil layer and established better fertilizer - root contact and then reduced weed competition (Singh, 2005; Cai *et al.*, 2002). The positive effect of N on root dry matter has been previously documented by Fageria (2009, 2010). Localized application of N can increase root density in the immediate area. Similar results were reported by Eissenstat and Caldwell (1998). The ability of the soil root system to meet the plants' N demand depends both on the ability of roots to absorb N from the soil at their surface and on the rate of delivery of the N to the root system (Kirk, 1994). In addition, the nutrients must be supplied to the root surface at a sufficient rate throughout the growth of the crop so that the crop does not suffer from inadequate nutrient supply. In practice, soil N supply in the root zone should be managed to match the quantity required by the crop (Cui *et al.,* 2008). This is particularly important during periods of rapid growth when nutrient demands are high (FAO, 2006). As ammonium concentrations at the placement sites decrease with time, presumably due to continued diffusion and/ or plant uptake, the rice roots may slowly proliferate through the placement sites. At this point, the spatial availability of USG - N may reach its peak, and it will then decline with time (Stangel, 1989). After USG application there is a lag time when urea becomes available for plant uptake and the availability increases with the depth of placement (Obcemea *et al*., 1984). The spatial availability of N seems to result in an improved relationship between deep placed USG (N source) and the rice plants (sink) as compared to the traditionally applied PU and rice plants (Chen *et al*., 1983).

Soil pH affected root growth of rice in the pot experiment. The highest root weight was observed on slightly acid soil. Shaaban *et al.* (2013) reported a negative relationship between root growth and soil pH. According to their findings root growth decreased when soil pH increased. They explained the observation to be due to salinity toxicity.

The numbers of tillers were higher in the acid soil than in the alkaline soil during the pot experiment. The type of urea fertilizer also affected tiller development. The numbers of tillers were higher with the use of USG than PU. This can be explained by the fact that, the availability of nitrogen favoured the cellular activity during plant growth and development, and led to an increase innumber of tillers (Rahman *et al*., 2007).

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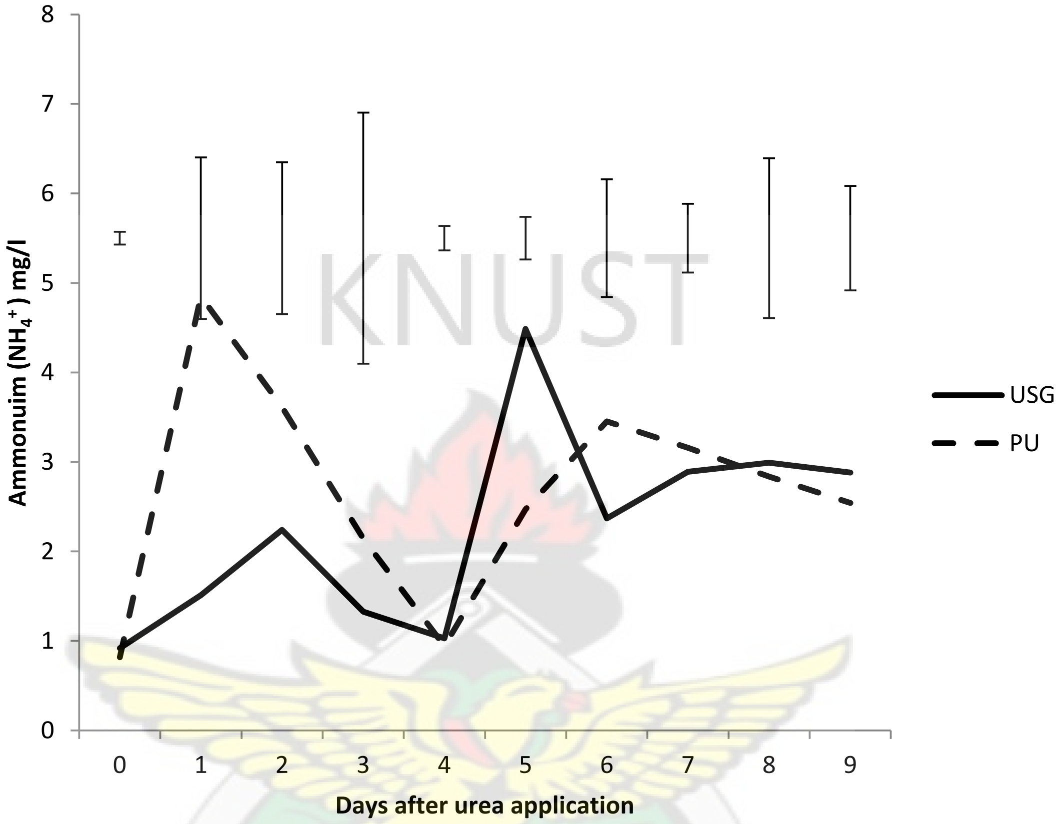
4.3 Effect of urea fertilizer type on ammonium concentration and pH in floodwater

4.3.1 Results on the effect of urea application on ammonium concentration and pH in floodwater

4.3.1.1 Ammonium concentration in floodwater after urea application during the wet season of 2012

After urea application, there was an increase in NH_4^+-N concentrations in the floodwater in all the plots. The NH_4^+-N concentration in floodwater increased and reached a peak value of 4.85 mg l^{-1} in one day after prilled urea application. In contrast, a peak of NH_4^+-N (4.49 mg l^{-1}) was observed 5 days after USG application (Figure 4.18). There was a significant (P<0.05) interaction between the treatment and the time of urea application even though half of PU rate (57 kg ha^{-1}) was applied 14 days after transplanting and the totality of USG rate (113 kg ha^{-1}) was deep placed 7 days after transplanting. Significant difference (P<0.05) was observed between the two treatments (PU and USG). The highest and lowest NH_4^+ concentration was recorded with PU (2.68 mg l^{-1}) and USG (2.26 mg l^{-1}), respectively.

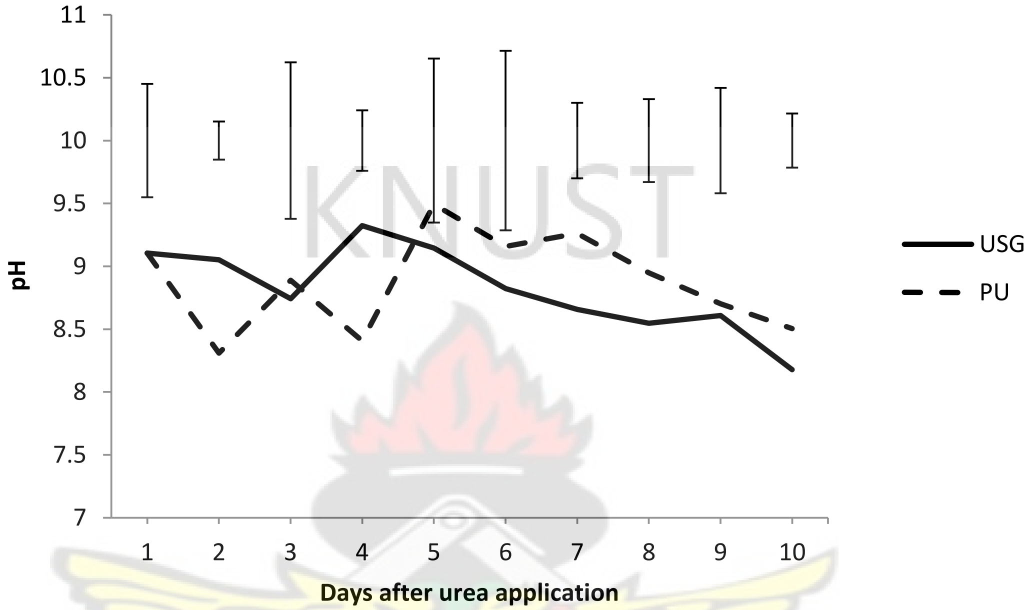


Bars indicate Lsd (5%)

Figure 4.18: Evolution of ammonium in floodwater after urea application in irrigated rice field in the wet season of 2012.

4.3.1.2 Changes in floodwater pH after urea application during the wet season of 2012

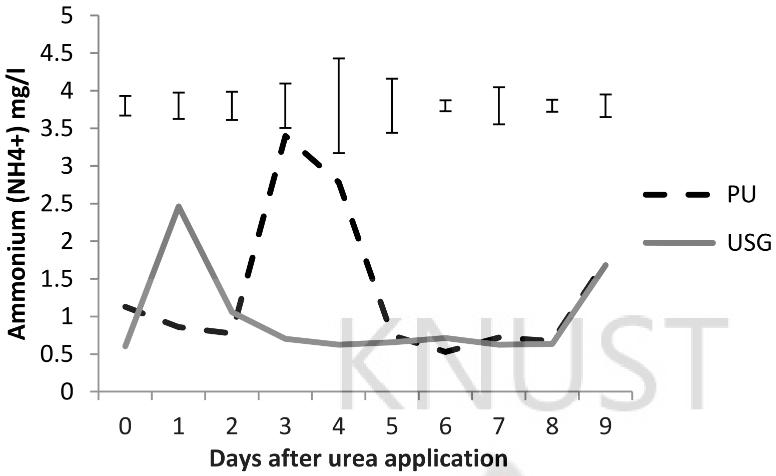
The pH value of floodwater fluctuated during 3 days after urea application in general. When PU was used a peak (pH = 9.49) was observed 5 days after urea application and then declined (Figure 4.19). Similar trend was observed with USG which peaked 4 days after urea application (pH = 9.32). Significant difference (P<0.05) was observed between the treatments and time.



Bars indicate Lsd (5%)

Figure 4.19: Changes in floodwater pH in irrigated rice field in the wet season of 2012.

4.3.1.3 Ammonium evolution in floodwater after urea application during the wet season of 2013

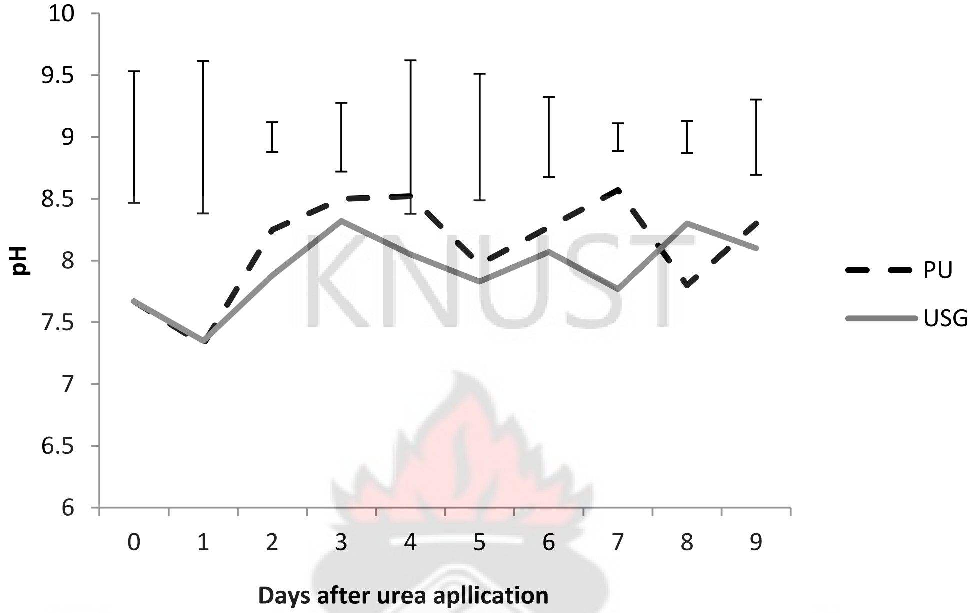


Bars indicate Lsd (5%)

Figure 4.20: Evolution of ammonium in floodwater after urea application in irrigated rice field in the wet season of 2013.

After urea application NH_4^+, concentration in floodwater treated with USG quickly increased and a peak value (2.46 mg l^{-1}) was observed in one day. A decrease of NH_4^+ concentration was observed with floodwater treated with PU one day after urea application. A peak value (3.40 mg l^{-1}) was observed 3 days after urea application. The concentration of floodwater (NH_4^+) increased after 8 days of urea application for the two treatments (Figure 4.20). A significant difference (P <0.05) was observed between the two treatments at half rate of PU and full rate of USG, the overall concentration of ammonium in the floodwater was higher when treated with PU (1.34 mg l^{-1}) than USG (0.98 mg l^{-1}).

4.3.1.4 Changes in floodwater pH after urea application during the wet season of 2013



Bars indicate Lsd (5%)

Figure 4.21: Changes of floodwater pH in irrigated rice field in the wet season of 2013.

Floodwater pH (Figure 4.21) followed a similar pattern with the two treatments after urea application. No significant difference was observed between USG and PU (half rate) after urea application. The differences were not significant also, but, the highest (8.12) and the lowest (7.96) floodwater pH values were observed with PU and USG, applied at half rate of PU and full rate of USG, respectively.

4.3.2 Discussion

4.3.2.1 Ammonium concentration in floodwater after urea application

The peak of NH_4^+ concentration was observed during the two seasons between one to 5 days after urea application. These results are in conformity with the findings of Fillery *et al*. (1984) who reported that urea hydrolysis takes place before one week after urea application. The peak of NH_4^+-N concentration from USG was reached 5 days after USG application in the 2012 cropping season and only one day after urea application in the 2013 cropping season. This difference can be attributed to the weather conditions during the cropping season. The temperature variation during the cropping season can affect urea hydrolysis (Dobermann and Fairhust, 2000). The amount of NH_4^+ in floodwater was significantly ($P<0.05$) higher in the floodwater with the PU treatment than the USG treatment during the two seasons. Rapid hydrolysis of urea leads to high concentrations of NH_4^+ in the floodwater especially when urea is broadcast directly in floodwater. Similar trends were reported by Snitwongse *et al*. (1988) and Craswell *et al.* (1981). This result can possibly be due to the fact that urea supergranules were deep placed in the soil (5 to 7 cm). Point placement of USG effectively hindered the escape of urea and ammoniacal - N in floodwater. This reduced the contact of urea with floodwater and then avoided the rapid hydrolysis of urea which caused elevation of NH_4^+ in floodwater. The elevated ammoniacal - N concentrations in floodwater after the application of urea highlight the potential for NH_3 volatilization from this N source (Freney *et al*., 1983). According to De Datta and Crasswell (1980), broadcast application of urea on the surface of soil causes losses up to 50%, but point placement of urea super granules (USG) in 10 cm depth may result in negligible loss. The possible reasons for the decline in NH_4^+-N concentrations in the treatments could have been assimilation of N by algae, NH_3 volatilization, nitrification and/or diffusion into the underlying soil layers (Thind and Rowel, 2000).

4.3.2.2 Effect of urea application on pH of floodwater

The increase in floodwater pH after urea application observed especially during the wet season of 2012 can be explained by the fact that the presence of urea N stimulates the growth of photosynthetic microorganisms. These, in turn increase the pH of the floodwater through CO_2 uptake (Stangel *et al.*, 1984). The importance of floodwater algae for transformations of applied N fertilizer is well recognized; mainly because they cause an increase in floodwater pH during the day (Thind *et al*., 2000; Mikkelsen *et al*., 1978; Simpson *et al*., 1988). The increase of floodwater pH can also be due to the inherent alkalinity associated with urea hydrolysis. Vlek and Craswell (l981) suggested that the reduction in pH often noted after the application of fertilizer N to non - buffered floodwater is the result of H^+ ion accumulation during NH_3 volatilization due to the presence of ammonia in floodwater. The increase in floodwater pH can also be attributed to the fact that the presence of floodwater induces anaerobic conditions that inhibit nitrification and favours nitrate reduction which, tends to increase floodwater pH (Dobermann and Fairhurst, 2000).

Floodwater pH tended to decrease in 3 days after USG application and 4 days after PU application in 2012. These results are in agreement with the findings of Vlek and Craswell (1981) who found that the hydrolysis of urea ends 3 to 4 days after urea application, which decreased the concentrations of $(NH_4)_2CO_3$ and also decreased the pH of floodwater. In the cropping season of 2013, the pH of floodwater fluctuated with the method of application. The flooded rice field is usually a temporary aquatic environment subject to large variations of pH. This fluctuation can be attributed to microbial activities. Roger (1996) reported that largest daily variations in pH occur at the beginning of the crop cycle when explosive blooms of microalgae develop after N fertilizer is broadcast in the floodwater. In fact, broadcasting method of N fertilizer encourages algal growth. According to their findings, the N loss resulted from a chemical process caused mostly by a marked increase in floodwater pH in relation to algal activity. This author (Roger, 1996) also reported that practices that decrease algal growth such as urea deep placement decrease diurnal variations in pH.

4.4 Effect of urea fertilizer type on rice yield components, yields and NUE

4.4.1 Results of the effect of urea fertilizer type on rice yield components, yields and NUE

4.4.1.1 Data of wet season of 2012

4.4.1.1.1 Tillers, panicles and thousand seed weight as affected by urea fertilizer type

Table 4.1 summarizes the effect of the treatments on yield components. Under type of urea, significant difference ($P<0.05$) was observed with the number of panicles. The highest and the lowest number of panicles were obtained with the treatment USG (224 m^{-2}) and the control (177 m^{-2}) respectively. Urea super granule gave 10 % more panicles than PU. Differences in the number of tillers on one hand and the 1000 seed weight were not significantly different among the different treatments. No interaction effects were observed with the combination of the different treatments and the two varieties. The combination between the two varieties (FKR19 and FKR62N) with USG gave greater number of tillers and panicles compared to the control and PU.

Table 4.1: Effect of urea fertilizer type on tillers, panicles and thousand seed weight.

Treatment	Tillers m^{-2}	Panicles m^{-2}	1000 seed weight (g)
Type of urea			
Control	249	177	20.10
PU	239	204	21.55
USG	269	224	20.86
Lsd (5%)	39	23	1.67
Fpr	0.271	0. 003	0. 208
Variety			
FKR 19	259	206	21.94
FKR 62N	246	196	19.73
Lsd (%)	31	74	12
Fpr	0.283	0. 712	0. 080
Variety×Type of urea			
FKR19 × Control	246	189	22.10
FKR19 × PU	253	212	22.75
FKR19 × USG	277	218	20.97
FKR62N × Control	252	165	18.10
FKR62N × PU	225	195	20.35
FKR62N × USG	262	230	20.75
Lsd (5%)	49	69	2.72
Fpr	0.649	0.253	0.080
CV(%)	14	11	7.3

4.4.1.1.2 Grain yield as affected by the type of urea fertilizer

Table 4.2 shows the results of rice grain yields during the wet season of 2012. Statistical analysis showed significant difference ($P<0.05$) between rice grain yields for the different treatments. The highest and the lowest grain yields were obtained with USG (5146 kg ha^{-1}) and the control (3156 kg ha^{-1}). The USG treatment produced average grain yield which were significantly different from PU treatment and the increase in grain yield with USG was 12% over PU. The increase in grain yield with USG and PU treatments over the control were 63% and 45%, respectively. Significant interaction effect was observed with the combination of urea treatments (PU and USG) and rice varieties (FKR19 and FKR62N). Grain yield of rice variety FKR19 was higher when it was fertilized with PU (5000 kg ha^{-1}) and the highest grain yields of rice variety FKR62N were obtained when the crop received with USG (5417 kg ha^{-1}).

Table 4.2: Effect of urea fertilizer type on rice grain and straw yields during the wet season of 2012.

Treatment	Grain yield (kg ha^{-1})	Grain yield Increase over control (%)	Straw yield (kg ha^{-1})	Straw yield Increase over control (%)
<u>Type of urea</u>				
Control	3156	-	3125	-
PU	4583	45.22	4292	37.34
USG	5146	63.05	5139	64.45
Lsd (5%)	358.9	-	412	-
Fpr	0.001	-	0.001	-
<u>Variety</u>				
FKR 19	4354	-	4264	
FKR 62N	4236	-	4106	
Lsd (5%)	359	-	985	-
Fpr	0.309	-	0.646	-
<u>Variety × Type of urea</u>				
FKR19× Control	3188	-	3125	-
FKR19 × PU	5000	56.86	4667	49.34
FKR19 × USG	4875	52.94	5000	60.00
FKR62N×Control	3125	-	3125	-
FKR62N × PU	4166	33.31	3917	25.34
FKR62N× USG	5417	73.33	5278	68.90
Lsd (5%)	454.6	-	*915*	-
Fpr	0.005	-	0.048	-
CV(%)	7.7	-	9	-

4.4.1.1.3 Straw yield as affected by the type of urea fertilizer

Highest and lowest rice straw yields were recorded with USG (5139 kg ha^{-1}) and the control (3125 kg ha^{-1}), respectively as shown in Table 4.2. The straw yield recorded in the wet season using USG was 21% higher than PU. The average increase in rice straw yields over the control with USG and PU were 64% and 37%, respectively.

The results revealed that there was significant interaction between varieties and N fertilizers. Urea supergranule application led to higher increases in the straw yields of the two varieties than the PU application. The increases in straw yields of the rice variety FKR 19 treated with USG and PU were 60 and 49%, respectively over the control. With rice variety FKR 62N, the increases over the control were 69 and 25% with USG and PU, respectively. The combination of FKR 62N and USG gave the highest straw yield (5278 kg ha^{-1}).

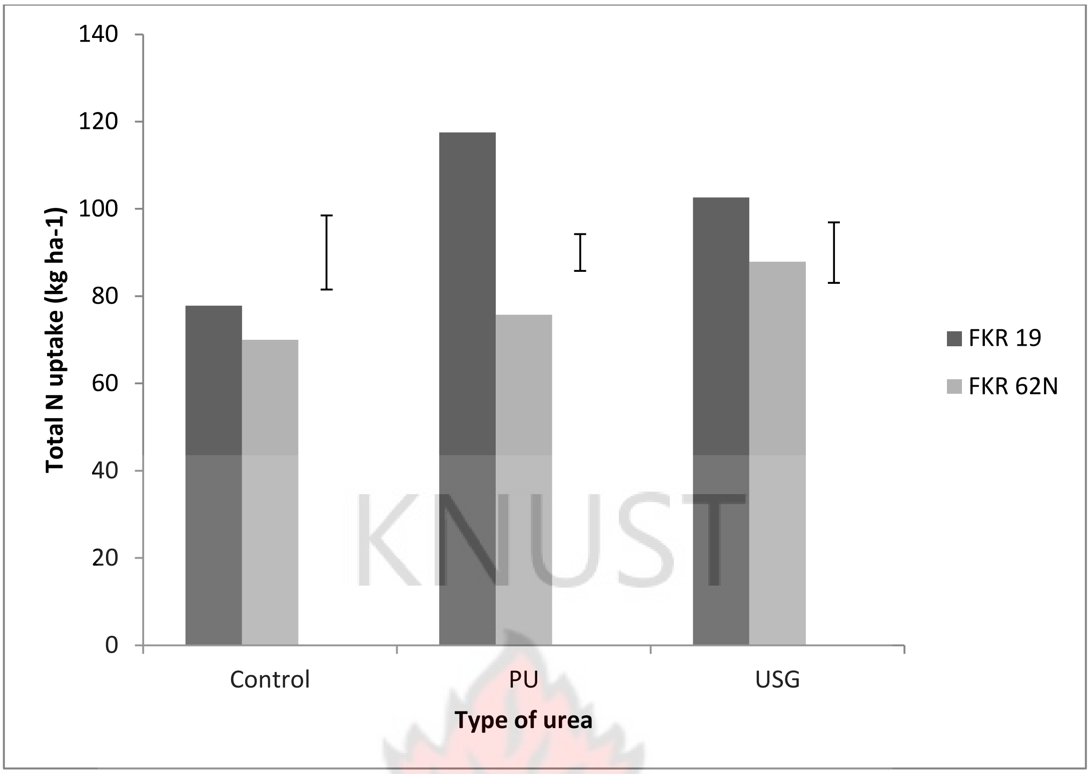
4.4.1.1.4 Effect of the type of urea fertilizer on grain and straw nutrient uptake

Rice grain and straw nutrient uptake were significantly ($P<0.05$) affected by urea fertilizer. The highest grain N, P and K uptake were observed with USG treatment as follows: 73.67, 2.71 and 41.01 kg ha^{-1}, respectively. The lowest grain nutrient uptake was observed with the control. The application of USG increased grain N uptake by 3%, P uptake by 6% and K uptake by 80% over PU (Table 4.3). Significant interaction ($P <0.05$) was between nutrient uptake and rice varieties. The highest P (3.36 kg ha^{-1}) and K (50.16 kg ha^{-1}) grain uptake was observed with USG treatment. Straw N, P and K uptake differed with fertilizer types. The lowest N, P and K uptake was obtained by the combination of FKR 19 on the control. The type of fertilizer significantly affected (P <0.05) straw N, P and K uptake. The highest straw N, P and K uptake was observed on the control (28.59 kg ha^{-1}), PU (0.84 kg ha^{-1}) and USG (116.75 kg ha^{-1}) respectively. The highest N and P was uptake recorded by the FKR 19 compared to FKR 62N. Significant effect was observed (P <0.05) with the combination between rice varieties and the type of urea on straw N and P uptake. The highest N (41.53 kg ha^{-1}) and P (1.21 kg ha^{-1}) uptake was obtained by the FKR 19 variety treated with PU.

Figure 4.22 shows the trends of total N uptake with the two varieties of rice. Significant differences (P<0.05) in total N uptake were observed between the two rice varieties and the type of urea. Total N uptake of rice variety FKR19 was higher than the variety FKR62N. The higher total N uptake was recorded by the FKR19 that received PU (117.53 kg ha^{-1}) and showed an increase of 15% over USG. Urea supergranule treatment significantly increased total N uptake of the rice variety FKR62N by 16% compared to PU.

Table 4.3: Effect of urea fertilizer type on rice grain and straw N, P and K uptake during the wet season of 2012.

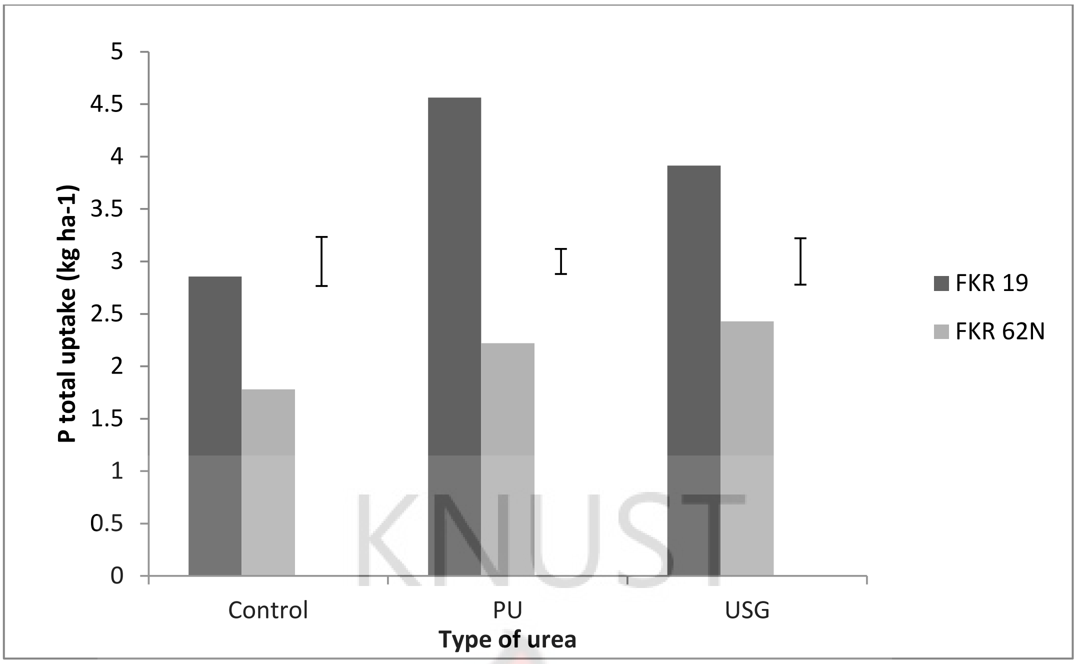
Treatments	Grain uptake (kg ha^{-1})			Straw uptake (kg ha^{-1})		
	N	P	K	N	P	K
<u>Type of urea</u>						
Control	45.31	1.82	10.46	28.59	0.50	10.46
PU	71.75	2.55	22.83	24.88	0.84	91.61
USG	73.67	2.71	41.01	21.61	0.46	116.75
Lsd (5%)	5.06	0.18	1.83	2.74	0.06	16.62
Fpr	0.001	0.001	0.001	0.001	0.001	0.001
<u>Variety</u>						
FKR 19	65.65	2.97	29.21	33.68	0.81	121.83
FKR 62N	61.51	2.71	20.32	16.38	0.39	127.88
Lsd (5%)	4.55	0.14	1.86	7.19	0.16	28.99
Fpr	0.063	0.001	0.001	0.005	0.004	0.554
<u>Variety×type of urea</u>						
FKR19 × Control	47.81	2.20	11.73	30.00	0.66	84.41
FKR19 × PU	76.00	3.35	26.75	41.53	1.21	119.38
FKR19 × USG	73.12	3.36	50.16	29.50	0.55	161.70
FKR62N × Control	42.81	1.44	9.19	27.19	0.34	98.81
FKR62N × PU	67.50	1.75	19.92	8.23	0.47	114.13
FKR62N × USG	74.20	2.06	31.85	13.72	0.37	170.68
Lsd (5%)	6.48	0.22	2.42	6.64	0.15	2.42
Fpr	0.156	0.001	0.001	0.001	0.001	0.554
CV(%)	7.3	6.9	6.8	10.1	9.5	6.8



Bars indicate Lsd (5%).

Figure 4.22: Total nitrogen uptake (grain and straw) by rice varieties FKR19 and FKR62 N as affected by type of urea fertilizer during the wet season of 2012.

The amount of phosphorus taken by the two varieties of rice was similar to total N uptake with the two varieties of rice as shown in Figure 4.23. Total P uptake of rice variety FKR19 was significantly higher than total P uptake of FKR62N for all the treatments. The highest total P uptake (4.56 kg ha^{-1}) was recorded by the interaction between FKR19 and PU.



Bars indicate Lsd (5%).

Figure 4.23: Total phosphorus uptake (grain and straw) byrice varieties FKR19 and FKR62 N as affected by type of urea fertilizer during wet season of 2012.

4.4.1.1.5 Nitrogen use efficiency as affected by type of urea fertilizer

Table 4.4 summarizes the effect of N fertilizer on nitrogen use efficiency. Agronomic efficiency (AE) was significantly ($P < 0.05$) affected by the treatments. Applying USG significantly increased AE by 39% over PU. The interaction effects between the rice varieties and the treatments were also significant at $P<0.05$ where, the best was FKR 62N and USG which significantly increased the AE by 120% over PU with the same variety.

Table 4.4: Effect of urea fertilizer type on nitrogen use efficiency.

Treatment	AE (kg/kg N)	RE (%)	PE (kg/kg N)
Type of urea			
Control	-	-	-
PU	27.44	48.00	76.78
USG	38.26	46.00	95.62
Fpr	<.001	NS	0.04
Lsd (5%)	3.8	-	17.35
Variety			
FKR 19	33.65	57	57.73
FKR 62N	32.05	36	114.67
Fpr	NS	NS	0.01
Lsd (5%)	-	-	31.39
Variety × type of urea			
FKR19 × Control	-	-	-
FKR19 × PU	34.86	67.00	46.17
FKR19 × USG	32.45	48.25	69.29
FKR62N × Control	-	-	-
FKR62N × PU	20.03	28.00	107.73
FKR62N × USG	44.07	44.00	121.95
Fpr	<.001	0.02	NS
Lsd (5%)	23.16	22	-
CV (%)	9.4	23.1	16.5

AE = Agronomic Efficiency; RE = Recovery Efficiency; PE = Physiological Efficiency

No significant difference (P > 0.05) was observed on nitrogen recovery (RE) among rice varieties. However, interaction effects between the rice varieties and N fertilizers were significant (P<0.05). The highest RE was obtained with FKR19 using PU (67%) that was not significantly different from RE using USG with the same variety.

The RE of the rice variety FKR19 was higher than the rice variety FKR 62N but this latter variety treated with USG significantly increased the RE by 57% than PU. Physiological efficiency (PE) was also significantly greater with USG than PU and the increase in PE using USG was 26% higher than PU. The interactions between the rice varieties and the type of urea were not significant.

4.4.1.2 Data of the dry season of 2013

4.4.1.2 1 Tillers, panicles and thousand seed weight as affected by the type of urea fertilizer

The treatments affected the number of tillers, the number of panicles and 1000 seed weight (Table 4.5). Significant differences ($P<0.05$) were observed the number of tillers, panicles and 1000 seed weight with the treatments. The highest and the lowest number of tillers were recorded by USG and the control treatment with 351 and 304 tillers m^{-2} respectively. Urea supergranule treatment significantly increased the number of tillers 15% more than PU treatment. Higher values were obtained with USG treatment on the number of panicles (344 m^{-2}) and 1000 seed weight (24.11g) respectively.

Even though, no interaction effects were observed between the rice varieties and N fertilizers on 1000 seed weight, the highest weight values were recorded with USG treatment. However, the combination of rice varieties and N fertilizers significantly ($P < 0.05$) increased the number of tillers and panicles. The two parameters were significantly increased with USG treatment and PU treatment with the two varieties of rice. The rice variety FKR19 and USG interaction produced highest number of tillers (355 m^{-2}) and panicles (347 m^{-2}).

Table 4.5: Effect of urea fertilizer type on rice tillers, panicles and thousand seed weight in the dry season of 2013.

Treatment	Tillers m^{-2}	Panicles m^{-2}	1000 seed weight (g)
Type of urea			
Control	304	301	23.26
PU	326	324	23.85
USG	351	344	24.11
Lsd (5%)	12	13	0.73
Fpr	0.001	0.001	0.055
Variety			
FKR 19	337	334	23.58
FKR 62N	300	296	23.66
Lsd (5%)	45	43	1.05
Fpr	0.076	0.067	0.822
Variety × type of urea			
FKR19 × Control	318	316	23.02
FKR19 × PU	339	340	23.85
FKR19 × USG	355	347	24.15
FKR62N × Control	289	287	23.50
FKR62N × PU	312	309	23.85
FKR62N × USG	346	342	24.07
Lsd (5%)	43	38	1.23
Fpr	0.001	0.001	0.831
CV(%)	4	4	2.9

4.4.1.2. 2 Grain yields as affected urea fertilizer type

Grain yield was significantly (P<0.05) affected by N fertilizers in the dry season (Table 4.6). The highest and the lowest grain yields were recorded by USG (7000 kg ha^{-1}) and the control (4362 kg ha^{-1}). The increases in grain yield over the control with USG and PU were 60.48 and 52.31%, respectively (Table 4.6). No interaction effect was observed between rice varieties and N fertilizers but, USG treatment increased rice grain yield more than PU. The best combination was given by FKR19 and USG (7375 kg ha^{-1}).

4.4.1.2.3 Straw yield as affected by the type of urea fertilizer type

Table 4.6 summarizes the effect of rice varieties and N fertilizers on rice straw yields. In the dry season of 2013, rice straw yield was not significantly different between the urea fertilizers, but the highest and lowest straw yields were obtained with USG (6375 kg ha^{-1}) and the control (5038 kg ha^{-1}) respectively. Straw yield of the rice variety FKR 62N was higher than the variety FKR19 with all the urea types and the best combination was given by FKR62N and USG treatment (7250 kg ha^{-1}). Urea supergranule treatment increased straw yields over the control of the rice varieties FKR62N and FKR19 by 30 and 22%, respectively.

Table 4.6: Effect of urea fertilizer type on rice grain and straw yields during the dry season of 2013.

Treatment	Grain yield		Straw yield	
	(kg ha^{-1})	Increase over control (%)	(kg ha^{-1})	Increase over control (%)
Type of urea				
Control	4362	-	5038	-
PU	6644	52.31	5869	16.49
USG	7000	60.48	6375	26.53
Lsd (5%)	819	-	1025	-
Fpr	0.001	-	0.084	-
Variety				
FKR 19	6395	-	5216	-
FKR 62N	5570	-	6378	-
Lsd (5%)	1077	-	1335	-
Fpr	0.093	-	0.070	-
Variety × type of urea				
FKR19 × control	4812	-	4500	-
FKR19 × PU	7038	46.26	5362	19.15
FKR19 × USG	7375	53.26	5500	22.22
FKR62N×control	3912	-	5575	-
FKR62N × PU	6250	59.76	6375	14.34
FKR62N × USG	6625	69.35	7250	30.04
Lsd (5%)	1240	-	1545	-
Fpr	0.997	-	0.790	-
CV(%)	13	-	17	-

4.4.1.2.4 Effect of urea fertilizer type on grain and straw N, P and K uptake

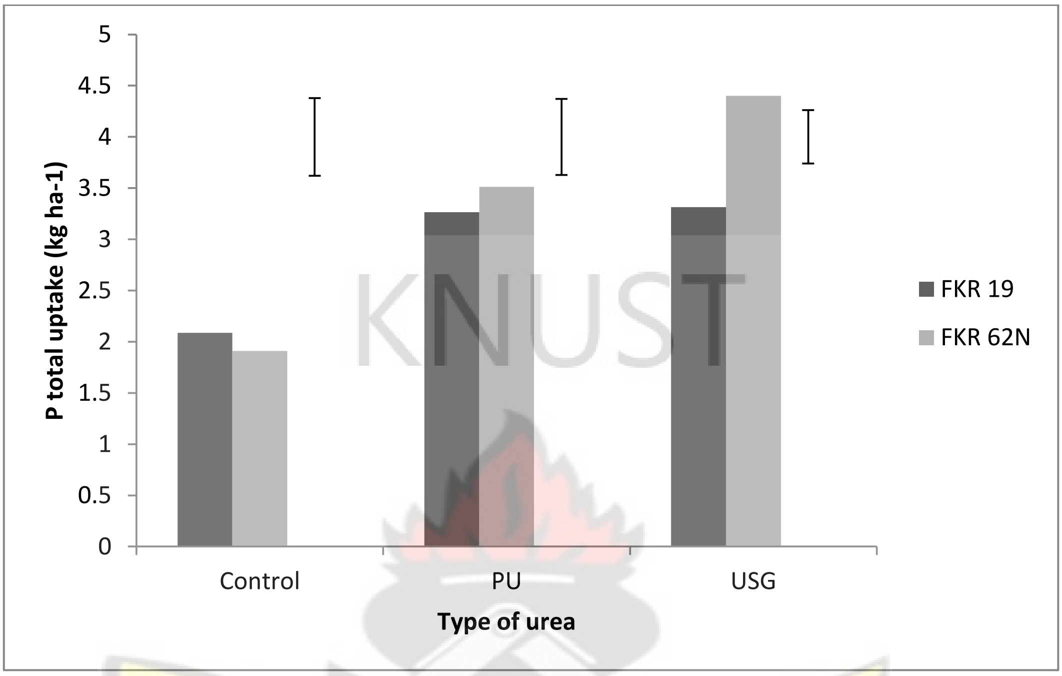
Table 4.7 summarizes the effects of the different treatments on grain and straw nutrient uptake. Significant differences ($P < 0.05$) were observed on grain N, P and K uptake. The highest grain N (106.77 kg ha^{-1}) and P (2.98 kg ha^{-1}) uptake were obtained with USG. The highest K uptake (46.26 kg ha^{-1}) was recorded with the PU treatment. The lowest N, P and K uptake were observed with the control and the values were 72.85, 1.52 and 27.49 kg ha^{-1}, respectively. Interactive effects between N fertilizers and rice varieties were significant only for grain P uptake and the effects of PU and USG varied with rice varieties. The best combination was obtained with rice variety FKR 62N and USG (3.31 kg ha^{-1}) that increased P uptake by 15% over PU with the same variety. No interaction effects were observed with N and K uptake, but the best combination was obtained with rice variety FKR 62N and USG and the values were 110.64 and 48.69 kg ha^{-1}, respectively.

The rice straw uptake was increased with the USG treatment. Significant differences ($P <0.05$) were observed with P and K uptake. The increase in P uptake over the control with USG and PU were 81 and 27%, respectively. Potassium uptake was increased by 33 and 20% with USG and PU, respectively. Interaction effects of varieties and N fertilizers were observed on P and K uptake. No interaction effects were observed on N uptake.

Table 4.7: Effect of urea fertilizer type on rice grain and straw N, P and K uptake in the dry season of 2013.

Treatment	Grain uptake (kg ha^{-1})			Straw uptake (kg ha^{-1})		
	N	P	K	N	P	K
Type of urea						
Control	72.85	1.52	27.49	49.02	0.48	126.33
PU	99.69	2.77	46.26	54.51	0.61	151.44
USG	106.77	2.98	46.03	55.46	0.87	167.78
Lsd (5%)	14.80	0.31	5.37	9.19	0.15	28.68
Fpr	0.001	0.001	0.001	0.466	0.001	0.026
Variety						
FKR 19	96.10	2.32	38.25	44.64	0.57	153.17
FKR 62N	93.85	2.53	41.61	60.70	0.74	143.87
Lsd (5%)	23.296	0.500	8.257	12.019	0.145	38.859
Fpr	0.778	0.273	0.285	0.024	0.031	0.502
Variety×type of urea						
FKR19 × Control	80.37	1.64	24.78	40.05	0.45	119.92
FKR19 × PU	95.01	2.67	46.59	46.65	0.59	171.49
FKR19 × USG	102.89	2.66	43.37	47.85	0.66	168.08
FKR62N × Control	65.34	1.41	30.20	57.98	0.50	132.74
FKR62N × PU	104.38	2.88	45.94	56.74	0.64	131.39
FKR62N × USG	110.64	3.31	48.69	63.07	1.09	167.47
Lsd (5%)	24.46	0.51	8.51	13.88	0.19	42.40
Fpr	0.225	0.029	0.398	0.647	0.024	0.155
CV(%)	14.8	11.7	12.3	16.6	20.7	17.7

Phosphorus taken by the two varieties of rice is shown in Figure 4.24. Total P uptake of rice variety FKR 62N was higher than total P uptake of FKR19 for all the urea types except for the control. The highest total P uptake (4.40 kg ha^{-1}) was recorded by the interaction between rice variety FKR 62N and USG.



Bars indicate Lsd (5%).

Figure 4.24: Total P uptake (grain + straw) of rice varieties FKR19 and FKR 62N as affected by urea fertilizer type.

4.4.1.2.5 Nitrogen use efficiency of rice as affected by urea fertilizer type

In the dry season of 2013 the effect of the type of urea was not significant on NUE (AE, RE and PE). However, the AE and the RE were higher with USG than PU. Even though no interaction effects were observed, USG treatment performed better with the rice variety FKR 62N than the rice variety FKR 19 (Table 4.8).

Table 4.8: Effect of urea fertilizer type on nitrogen use efficiency during the dry season of 2013.

Treatment	AE (kg N kg^{-1})	RE (%)	PE (kg N kg^{-1})
Type of urea			
Control	-	-	-
PU	43.87	57.00	61.83
USG	45.31	76.00	54.72
Fpr	NS	NS	NS
Lsd (5%)	-	-	-
Variety			
FKR 19	40.62	48	61.57
FKR 62N	48.56	85	54.98
Fpr	NS	NS	NS
Lsd (5%)	-	-	-
Variety × type of urea			
FKR19 × Control	-	-	-
FKR19 × PU	42.79	41.00	69.65
FKR19 × USG	38.46	55.00	53.49
FKR62N × Control	-	-	-
FKR62N × PU	44.95	73	54.02
FKR62N × USG	52.16	97	55.94
Fpr	NS	NS	NS
Lsd (5%)	-	-	-
CV%	40.8	63.4	22.0

AE = Agronomic Efficiency; RE = Recovery Efficiency; PE = Physiological Efficiency

4.4.1.3 Data of wet season of 2013

4.4.1.3.1 Tillers, panicles and thousand seed weights as affected by urea fertilizer type

Table 4.9 summarizes the effect of N fertilizer on yield components. The number of tillers and panicles were not significantly ($P > 0.05$) affected by urea type. However, the highest and lowest numbers of tillers were recorded with USG treatment. The same trend was observed with the number of panicles in which the highest value was obtained with USG (234 panicles m^{-2}). Unlike the dry season of 2013, the interactive effects between variety and urea type on the number of tillers and panicles were not significant.

Table 4.9: Effect of urea fertilizer type on rice tillers, panicles and thousand seed weight during the wet season of 2013.

Treatment	Tillers m^{-2}	Panicles m^{-2}	1000 seed weight (g)
Type of urea			
Control	181	178	20.98
PU	229	223	20.47
USG	233	234	20.78
Lsd (5%)	23	22	0.59
Fpr	0.001	0.001	0.198
Variety			
FKR 19	213	209	18.63
FKR 62N	218	215	22.86
Lsd (5%)	29	36	0.958
Fpr	0.583	0.633	0.001
Variety × type of urea			
FKR19 × Control	164	163	19.17
FKR19 × PU	240	231	17.90
FKR19 × USG	234	233	18.82
FKR62N × Control	198	193	22.80
FKR62N × PU	218	215	23.03
FKR62N × USG	240	236	22.73
Lsd (5%)	33	36	0.97
Fpr	0.060	0.116	0.037
CV(%)	9.9	9.7	2.6

4.4.1.3.2 Grain yields as affected by urea fertilizer type

Grain yields are presented in Table 4.10. Grain yield was significantly ($P < 0.05$) affected by urea fertilizer type. The highest and the lowest grain yields were recorded with USG treatment and the control. The increases in grain yield over the control with USG and PU treatments were 55 and 37%, respectively.

Unlike the dry season of 2013, interaction effects were observed between rice varieties and the urea fertilizer type. The highest grain yield (2996 kg ha^{-1}) was obtained by the rice variety FKR62N treated with USG. The increase in grain yield with this combination was 90% over the control with the same rice variety.

4.4.1.3.3 Straw yields as affected by urea fertilizer type

Table 4.10 summarizes the effects of urea fertilizer type on straw yield. The PU and USG significantly ($P < 0.05$) increased straw yields by 58 and 72% over the control. The USG treatment out yielded the PU treatment by 13.6%. No variety and fertilizer interaction effect on straw yield was observed.

Table 4.10: Effect of urea fertilizer type on rice grain and straw yields during the wet season of 2013.

Treatment	Grain yield		Straw yield	
	(kg ha^{-1})	Increase over control (%)	(kg ha^{-1})	Increase over control (%)
Type of urea				
Control	1774	-	3021	-
PU	2439	37.49	4771	57.93
USG	2746	54.79	5182	71.53
Lsd (5%)	264	-	633	-
Fpr	0.001	-	0.001	-
Variety				
FKR 19	2194	-	4297	-
FKR 62N	2445	-	4352	-
Lsd (5%)	199.5	-	696.5	-
Fpr	0.028	-	0.819	-
Variety × type of urea				
FKR19×Control	1975	-	3187	-
FKR19 × PU	2112	6.49	4790	50.30
FKR19 × USG	2495	26.33	4915	54.22
FKR62N×Control	1574	-	2854	-
FKR62N × PU	2766	75.73	4752	66.50
FKR62N × USG	2996	90.34	5450	90.96
Lsd (5%)	327	-	858	-
Fpr	0.002	-	0.348	-
CV(%)	10.5	-	13.4	-

4.4.1.3.4 Effect of urea fertilizer type on rice grain and straw N, P and K uptake

The type of urea fertilizer significantly affected ($P < 0.05$) rice N, P and K uptake as presented in Table 4.11. Application of USG significantly outperformed PU in terms of N, P and K uptake by the rice grain. The increases in N, P and K uptake with USG over PU were 25, 16 and 42 %, respectively.

The variety FKR62 N was significantly ($P < 0.05$) superior to FKR19 in relation to the uptake of the other major nutrients by the grain

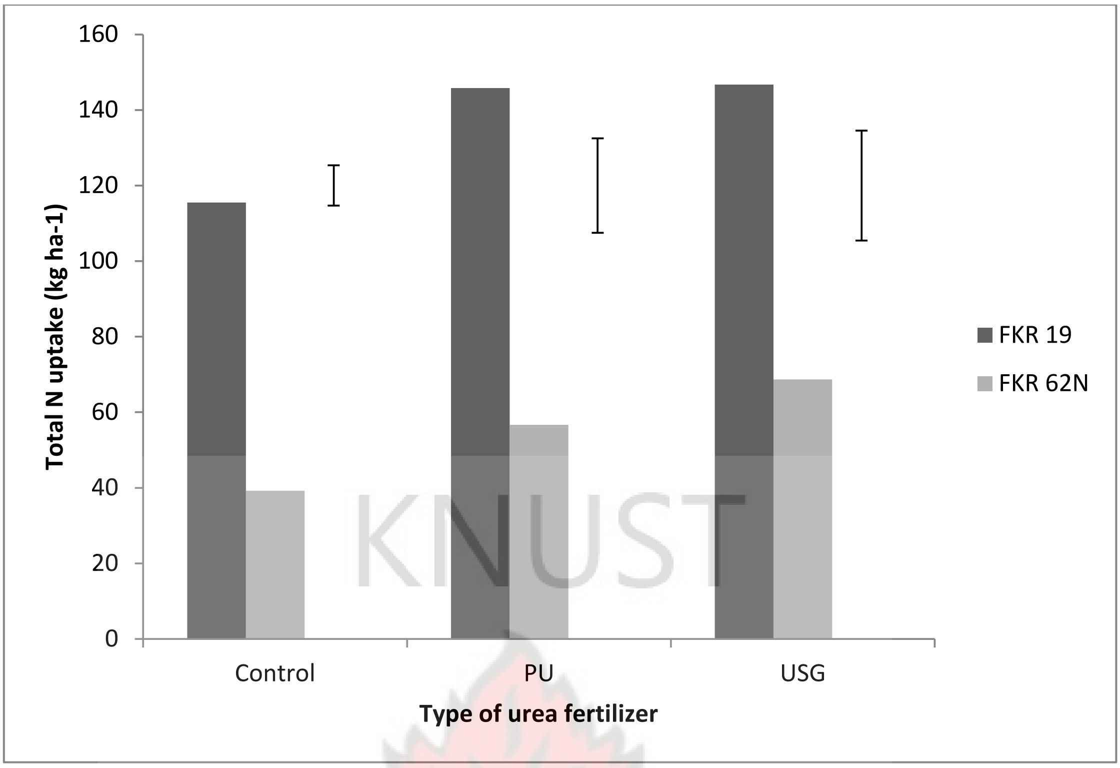
Straw N, P and K uptake was also significantly affected by the urea fertilizer type. The differences in N and K between the two fertilizers were not significant.

The variety and fertilizer urea interactions on the N, P and K uptake by the rice straw were significant ($P<0.05$). Greater amounts of N, P and K were significantly absorbed by the FKR62N rice variety compared to the FKR19 variety.

Table 4.11: Effect of urea fertilizer type on rice grain and straw N, P and K uptake during the wet season of 2013.

Treatment	Grain uptake (kg ha^{-1})			Straw uptake (kg ha^{-1})		
	N	P	K	N	P	K
Type of urea						
Control	22.98	2.72	5.48	54.40	2.93	75.60
PU	29.70	4.63	6.41	71.50	4.14	132.90
USG	37.16	5.39	9.08	70.40	6.80	132.50
Lsd (5%)	3.50	0.49	0.82	8.22	0.67	17.91
Fpr	0.011	0.001	0.001	0.001	0.001	0.001
Variety						
FKR 19	27.65	3.66	6.55	108.2	7.39	97.4
FKR 62N	32.24	4.84	7.44	22.6	1.85	129.9
Lsd (5%)	2.56	0.42	0.57	8.27	0.66	19.22
Fpr	0.001	0.003	0.016	0.001	0.001	0.013
Variety × type of urea						
FKR19 × control	25.58	3.33	6.46	89.9	4.37	65.40
FKR19 × PU	25.08	4.28	6.04	120.70	6.56	127.70
FKR19 × USG	32.31	3.37	7.14	114.00	11.26	99.10
FKR62N × control	20.38	2.13	4.50	18.8	1.48	85.80
FKR62N × PU	34.33	4.98	6.78	22.30	1.71	138.10
FKR62N × USG	42.01	7.42	11.02	26.70	2.34	165.80
Lsd (5%)	4.31	0.62	1.00	10.83	0.88	24.08
Fpr	0.001	0.001	0.001	0.011	0.001	0.011
CV(%)	10.7	10.6	10.7	11.5	13.3	14.5

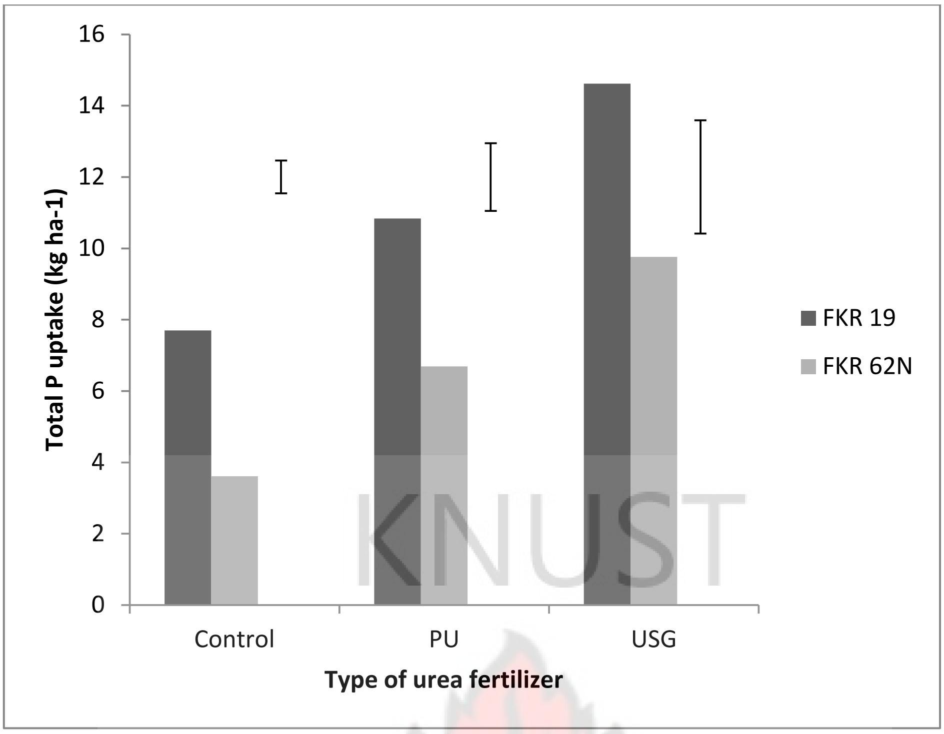
On the average, the total N uptake of the rice variety FKR 19 was significantly ($P < 0.05$) higher than the FKR 62N (Figure 4.25).



Bars indicate Lsd (5%).

Figure 4.25: Total N uptake (grain and straw) by the rice varieties and type of urea fertilizer.

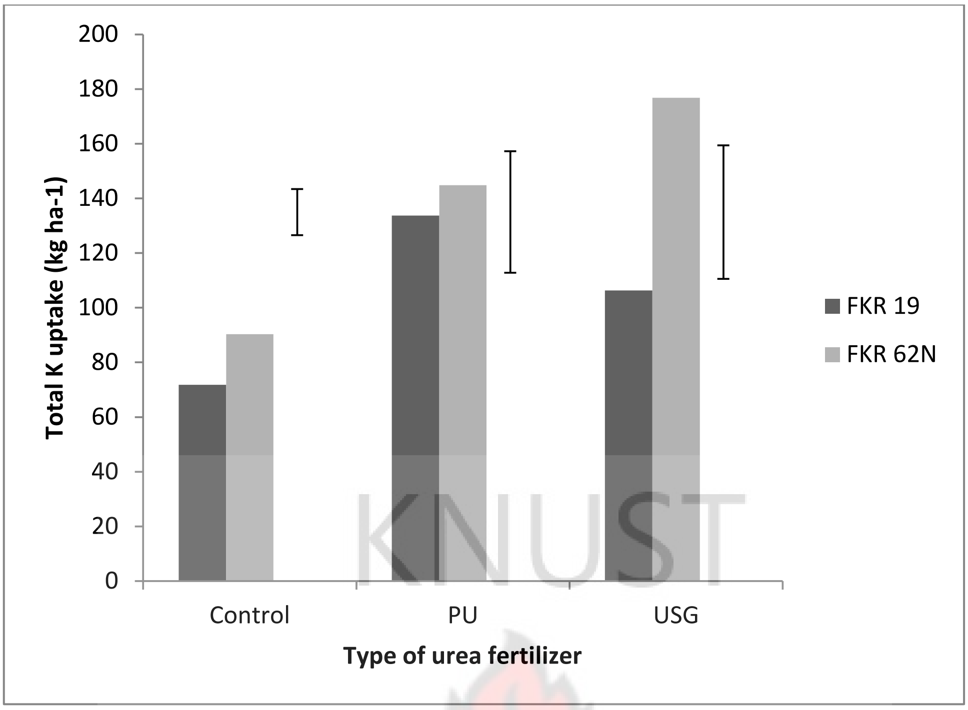
Figure 4.26 shows the effects of the type of urea fertilizer on the total P uptake of rice varieties. Total P uptake was significantly ($P < 0.05$) affected by the rice varieties and the type of urea. The use the urea fertilizer type led to higher total P uptake by FKR 19 than FKR62N.



Bars indicate Lsd (5%).

Figure 4.26: Total P uptake (grain and straw) with varieties and type of urea fertilizer.

Total K uptake was significantly (P <0.05) affected by the uptake of rice variety and the type of urea. Unlike total N and total P uptake, the highest total K was obtained by the rice variety FKR 62N to which USG was applied (Figure 4.27).



Bars indicate Lsd (5%).

Figure 4.27: Total K uptake (grain and straw) by the varieties and urea fertilizer type.

4.4.1.3.5 Nitrogen use efficiency as affected by the urea fertilizer type

The Table 4.12 summarizes the effect of urea fertilizer type on rice nitrogen use efficiency. Unlike the dry season of 2013, NUE was affected by the urea fertilizer type. The agronomic efficiency was significantly (P <0.05) affected by the type of urea fertilizer. The USG treatment was significantly and more efficient (46%) than the PU treatment.

Table 4.12: Effect of the urea fertilizer type on rice Nitrogen use efficiency in the wet season of 2013.

Treatment	AE (kg N kg^{-1})	RE (%)	PE (kg N kg^{-1})
Type of urea			
Control	-	-	-
PU	12.80	56.70	35.00
USG	18.70	63.40	33.50
Fpr	0.03	NS	NS
Lsd (5%)	5.02	-	-
Variety			
FKR 19	6.3	66.0	10.8
FKR 62N	25.1	45.1	57.6
Fpr	0.02	NS	0.002
Lsd (5%)	13.68	-	13.38
Variety × type of urea			
FKR19 × Control	-	-	-
FKR19 × PU	2.60	72.60	5.40
FKR19 × USG	10.00	59.40	16.20
FKR62N × Control	-	-	-
FKR62N × PU	22.90	40.90	64.50
FKR62N × USG	27.4	67.30	50.80
Fpr	NS	0.02	0.02
Lsd (5%)	-	37.08	13.05
CV (%)	26.1	20.3	21.1

AE = Agronomic Efficiency; RE = Recovery Efficiency; PE = Physiological Efficiency

The RE and PE were not significantly different with the urea fertilizer types, but the interaction with rice varieties and N fertilizer was significant. The RE was higher with rice variety FKR19 using PU and the increase over USG was 22%. The combination of the rice variety FKR 62N and USG gave the highest RE compared to PU with the same variety and the increase over PU was 65%. The interaction between rice varieties and the urea fertilizer type had a significant effect on the PE. The highest PE with rice varieties FKR19 and FKR 62N were observed with USG (16.20 kg N kg^{-1}) and PU (64.50kg N kg^{-1}), respectively.

4.4.1.4. Relationship among grain yield, NUE and grain N uptake in the wet seasons of 2012 and 2013

Grain yield was linearly related to grain N uptake, AE and PE with the use of PU (Table 4.13). The grain yield increased with the increasing grain N uptake and AE. However, increasing PE decreased grain yield. The RE was not significantly related to the grain yield. A multiple regression describing the relationship between grain yield, NUE and grain N uptake is indicated by the Equation 4.1.

Grain yield was positively related to all the parameters with the use of USG, but the relationship was significant with grain N uptake and the PE (Table 4.14 and Equation 4.2).

Table 4.13: Multiple regression of grain yield with NUE parameters and grain N uptake using PU.

Parameter	Coefficients	Standard Error	Significance
Constant	903.40	130.56	<0.001
RE	-30.06	178.97	0.87
PE	-2.84	1.26	0.04
AE	12.88	2,60	<0.001
Grain N uptake	49.71	1.78	<0.001

$Y_{\text{Grain yield}}$ = 903.40(±130.56) + 49.71(±1.78) Grain N uptake + 12.88(±2.60) AE-2.84(±1.26)PE (Equation 4.1).

R^2 = 0.99, P <0.001

Table 4.14: Multiple regression of Grain yield with NUE parameters and grain N uptake using USG.

Parameter	Coefficients	Standard Error	Significance
Constant	301.80	191.84	0.14
RE	263.74	253.93	0.32
PE	4.72	1.86	0.03
AE	4.01	5.37	0.47
Grain N uptake	55.75	4.26	<0.001

$Y_{\text{Grain yield}}$= 55.75(±4.26) Grain N uptake +4.72(±1.86) PE (Equation 4.2)

R^2= 0.99, P <0.001

4.4.2 **Discussion**

4.4.2.1 Effect of urea fertilizer type on N, P and K uptake

Generally, urea deep placement with USG increased N, P and K uptake during the three cropping seasons. This result was in agreement with the findings of Nie *et al.* (2009) who reported that N uptake was high when USG was used as source of nitrogen. Pot experiment study also demonstrated that N, P and K uptake were higher with USG. This could be explained by the fact that USG increased root dry matter and soil N availability during rice development stages. The development of rice rooting system favoured nutrient uptake. Urea Deep Placement (UDP) technology has proved to be highly effective in improving crop uptake of applied nitrogen fertilizers in irrigated rice system in Asia (Bowen *et al.,* 2004; Pasandaran *et al.*, 1999).

The uptake of N, P and K differed with the combination of urea fertilizer type (USG and PU) and the rice varieties (FKR19 and FKR62N). Uptake of the nutrients was higher with rice variety FKR19 using PU while the rice variety FKR62N showed higher uptake of the nutrients by using USG. This result could be explained by the genotypic difference of the two rice varieties and the relation between root environment and rice plant.

4.4.2.2 Rice yields components, grain and straw yields and as affected by urea fertilizer type

Effect of urea fertilizer type on yield components

The type of urea fertilizer affected panicle and tiller development. Urea deep placement using USG increased yield components throughout the three cropping seasons. These results are in conformity with the findings of Mamum *et al.* (2013), that deep placement of USG produced significantly higher number of bearing tillers m^{-2} than PU application at harvest. This result could be explained by the fact that nitrogen supply with USG was synchronized with plant demand for N. Probably the continuous availability of N from USG played a vital role in cell division due to higher photosynthetic activities for the availability of N that helped in increasing the number of tillers. The slow release of nitrogen from USG ensured long time supply of N to the rice plants and helped to produce higher panicles and tillers. These results are in agreement with the findings of Hasanuzzaman *et al*. (2012) and Masum *et al*. (2008) who reported that the placement of N fertilizer in the form of USG produced the highest number of effective tillers $hill^{-1}$, filled grains $panicle^{-1}$ which ultimately gave higher grain yield. During the study in the two wet seasons the concentration of ammonium in floodwater was less with USG compared to PU. The highest yield components observed with deep placement of USG could be due to reduced loss of N from soil using USG. Similar results were reported by Islam *et al*. (2013) who found highest growth parameters using USG. Guindo *et al*. (1994) and Liu *et al*. (2007) reported that the absorbed N used for rice straw and leaf growth at the tillering stage was transported to the panicles at advanced developmental stages. Even though seed weight is one of the components of yield, the thousand seed weight was not influenced by type of urea during the three cropping seasons.

Effect of urea fertilizer type on grain and straw yields

Fertilizer deep placement significantly increased rice grain and straw yields during the three cropping seasons. The grain yield increases with urea deep placement using USG over broadcasting method with PU ranged between 8 to 18% and the straw yield increases with USG over PU ranged between 10 to 27%. The study of Mamun *et al*. (2013) and BRRI (2008) reported that USG was superior source of N over PU. The incorporation of USG into the soil prevented the release of ammonium into floodwater and reduced ammonia losses. Lower amount of ammonium was observed in the field with USG treatment compared to PU. The increases in grain and straw yields could be attributed to the availability of N fertilizer that could increase rice growth. These differences can be ascribed to the slow release of N from USG over the period of 65 days in synchrony with the plant demand as observed by Gaudin (1988). These results are in agreement with the findings of Bowen *et al*. (2004), Pasandaran *et al*. (1999) and Yaméogo *et al.* (2013) who reported positive relation between grain yield and N uptake. In fact, the pot experiment confirmed that the use of USG significantly increased the amount of nitrogen in soil and increased the uptake of nutrients (N, P and K) for growth. Crop growth requires that nutrients be present in soil in adequate amounts and in suitable forms for uptake. The translocation of N during panicle development at advanced stages (Guindo *et al.*, 1994; Liu *et al*., 2007) increased rice grain yields. Jiang *et al*. (2004) and Duan *et al.* (2005) also reported that the key period for N absorption by rice plants is from tillering to flowering. During this period the absorption of soil N is at its maximum rate. Most of the absorbed N is stored in the leaves and may be transported to the grains during grain filling. Apparently, the increase in N uptake positively influences the number of tillers and panicles produced per m^2, resulting in yield increase (Yoshida et *al*., 1972). Bandaogo (2010), Jing *et al*. (2013), Debnath *et al* .(2013) and Yaméogo *et al*. (2013) reported that fertilizer deep placement using USG can increase grain yield ranging between 500 and 1700 kg ha^{-1} over PU. Pot experiment also confirmed that the technology of USG increased root growth at earlier stage to the maturity of rice plant. Root development induced by the use of USG facilitates the interception of many nutrients by growing plant roots and significantly increased plants' nutrient uptake. The lower yields recorded with PU compared with could be explained by the fact that prilled urea (PU) is a fast releasing nitrogenous fertilizer which is usually broadcast directly in the floodwater that causes considerable losses as ammonia volatilization, denitrification, and leaching.

The highest grain yield (7000 kg ha^{-1}) was recorded in the dry season compared with the two wet seasons. Similar results were reported by Cassman and Pingali. (1995) and Sheehy *et al*. (2011), who found that the yield of paddy rice in the dry season was significantly higher than in the rainy season. This result can be explained by the fact that seasonal differences in insolation between wet and dry seasons lead to differences in rice yield. The higher grain and straw yields recorded in the dry season can be explained by higher solar radiation and photosynthetic activity, which led to more dry matter production. Jianquan *et al*. (2013) reported that high nitrogen content in vegetative tissue is advantageous; especially during grain filling as the extended high rates of photosynthesis provide additional photo assimilates and stem reserves that compensate for any loss through sufficient assimilate translocation. Savant and Stangel (1990) also reported that the patterns of deep-placed USG - N uptake by the rice plants appear to be influenced by season.

During the study, the performance of the two rice varieties differed with the type of urea fertilizer. Deep placement of urea seemed to perform better with rice variety FKR62N. Higher grain and straw yields were observed with USG combined with this variety compared to rice variety FKR 19. This result is in agreement with the findings of Patel (2000) who also reported that yield performance varied with rice variety.

4.4.2.3 Effect of urea fertilizer type on Nitrogen use efficiency

Agronomy efficiency significantly increased with USG application ($P < 0.001$) in the two wet seasons and the increase over PU ranged between 39 and 46%. This result is in agreement with the findings of Savant and Stangel (1990) that the agronomic performance of deep placed USG was found to be superior to that of two or three split applications of PU. The superiority of USG over broadcasting method of PU was recorded mainly for the rice variety FKR 62N. In the wet season of 2012 urea deep placement with USG increased the AE of the rice variety FKR 62N by 120 %. Wang *et al*. (2005) reported that N use efficiency is variable among rice genotypes. FKR 62N absorbed higher amounts of N, leading to greater yield performance and NUE. Plant factors such as plant type and plant cycle can influence the agronomic performance of deep placed USG (Savant and Stangel, 1990).

The grain yield was closely related to the agronomic efficiency ($P < 0.05$). A positive linear correlation was observed between grain yield and AE during the wet cropping seasons. The result is in agreement with the findings of Fageria *et al*. (2010) who also reported a high relationship between grain yield and agronomic efficiency.

These studies reveal that the technology of USG is effective in increasing fertilizer N use efficiency of irrigated rice as compared to the traditional broadcast application of PU in West Africa. Studies conducted in Asia also invariably showed the superiority of USG over PU (Hassan *et al*., 2002; Mohanty *et al*., 1999). Deep placement of urea in anaerobic soil layer limits the concentration of N in floodwater and in the surface oxidized layer, leading to reduced N losses via runoff, ammonia volatilization and denitrification; and this resulted in increased fertilizer N use efficiency and improved yield gains (Kapoor *et al*., 2008).

N uptake and use efficiency varied among the tested rice varieties. The genotypic difference in the rooting system, nutrient uptake and grain filling capacity of FKR19 and FKR62N may vary as nutrients are transported to the panicles (translocation) during grain filling, these factors are likely to cause difference in NUE. Many authors reported the influence of genotypic traits, such as plant type and growth duration on the nutrient use efficiency (Jiang *et al*., 2004; Duan *et al*., 2005; Fageria *et al*., 2010).

The results indicated that nitrogen recovery (RE) and nitrogen physiological efficiency (PE) varied between the two rice varieties with the different application method. The RE was higher with the variety FKR19 using PU and the increase over USG ranged between 19 and 67% during the two wet seasons. With the variety FKR62N the RE was higher with USG treatment and the increase over PU ranged between 57 and 65% during the two wet seasons. In contrast, significant effect ($P < 0.05$) was observed with the PE in the wet season of 2013 where, PE increased with

USG and PU with the rice variety FKR 19 and FKR 62N, respectively. This can be explained by the difference in nutrient uptake by the two varieties or might be due to the difference in the rooting systems. It is known that a well developed root system is obviously essential for rice plants to effectively absorb available nutrients. Previous studies reported that there was great potential for NUE improvement by changing accumulation and redistribution of dry matter and N under optimal N management in different cultivars (Jiang *et al.*,2003, 2004; Wen-xia *et al*., 2007). Likewise, Sheehy *et al*. (2006) reported that nitrogen recovery was genotype-specific. In the wet season 2012, the PE increased by 26% over PU using USG. Most research concerned with improving N use efficiency of irrigated rice has focused on the reduction of N losses from applied fertilizer. Physiological Efficiency was negatively related to grain yield with USG treatment and PU treatment in the two wet seasons, respectively. These results can be explained by the inefficient use of N absorption by rice plant with the use of PU. The results also indicated that AE and RE were significantly associated ($P<0.05$) in the wet season of 2012, suggesting that improving fertilizer N recoveries can also result in increased N agronomic efficiency. Similar results were reported by Fageria *et al*. (2010).

4.5 Evaluation of rice response to urea supergranule and different levels of phosphorus

4.5.1 Results of the evaluation of rice response to urea supergranule and different levels of phosphorus

4.5.1.1 Data of the wet season of 2012

4.5.1.1.1 Rice tillers, panicles and 1000 seed weight

Yield component responses to USG and phosphorus levels are summarized in Table 4.15. Statistical analysis did not show any interaction effect between USG and phosphorus on the number of tillers, number of panicles and 1000 seed weight. The results indicated that the number of tillers and the number of panicles were significantly influenced by phosphorus application. Application of phosphorus at the rate of 40 kg P ha^{-1} produced the highest of tillers (275 tillers m^{-2}) and panicles (245 panicles m^{-2}). The response of 1000 seed weight to USG and phosphorus was not significant.

Table 4.15: Effect of USG and phosphorus on rice tillers, panicles and 1000 seed weight.

Treatment	Tillers m^{-2}	Panicle m^{-2}	1000 seed weight (g)
1.8g USG	235	196	22.8
2.7g USG	253	206	23.1
Lsd (5%)	22	40	1.3
Fpr	0.087	0.417	0.455
Phosphorus rate (kg ha^{-1})			
P_0	207	168	22.7
P_{20}	252	206	22.1
P_{30}	243	199	23.2
P_{40}	275	245	23.3
P_{50}	243	190	23.3
Lsd (5%)	35	38	1.3
Fpr	0.010	0.006	0.257
Fpr USG x P	0.287	0.959	0.647
CV	13.9	18.4	5.4

4.5.1.1.2 Rice grain yield response to USG and different levels of phosphorus

The results of this study indicated that there was no significant ($P<0.05$) difference between the USG 1.8 g and USG 2.7 g. However, grain yield was significantly influenced ($P<0.001$) by phosphorus fertilizer. Table 4.16 shows that the highest and the lowest grain yield were recorded at P_{50} and P_0, respectively. The highest yield of 4556 kg ha^{-1} was 107% more than the control**.** The P_{20} and P_{50} rates increased grain yield by 62% to 107%, respectively over the control (P_0).

4.5.1.1.3 Rice straw yield response to USG and different levels of phosphorus

There was no significant difference ($P<0.05$) in straw yield with USG1.8 g and 2.7 g. The application of phosphorus significantly ($P<0.05$) increased straw yield. Straw yields increased with increasing P up to 50 kg ha^{-1} with 20 kg P ha^{-1} producing optimum (Table 4.16). Straw yield differences with P20 and above were not statistically significant. Yield increase over the treatment P_0 ranged from 58 to 40%. No significant interaction was observed with the combination of nitrogen and phosphorus.

Table 4.16: Effect of USG and phosphorus on rice grain and straw yield during the wet season of 2012.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Type of urea		
1.8g USG	3767	3475
2.7g USG	3825	3900
Lsd (5%)	4.6	553.1
Fpr	0.670	0.092
Phosphorus rate (kg ha^{-1})		
P_0	2250	2625
P_{20}	3636	3688
P_{30}	4250	3938
P_{40}	4188	4031
P_{50}	4556	4156
Lsd (5%)	643.2	792.6
Fpr	0.001	0.004
Fpr USG × P	0.661	0.087
CV (%)	16.4	20.8

4.5.1.1.4 Nitrogen, phosphorus and potassium uptake by rice grain and straw with USG and phosphorus

Table 4.17 summarizes the N, P and K uptake of rice grain and straw after harvest. No significant difference was observed in N, P and K grain uptake with USG 1.8 g and 2.7 g. However, the application of P significantly ($P < 0.05$) increased grain N, P and K uptake. N uptake increased with the increasing P rates up to 74.3 kg ha^{-1}. The uptake of grain P was highest at P_{40} and the least uptake was observed at 0P. Grain P upatke ranged from 0.73 to 1.73 kg ha^{-1}. The amount of K partitioned into rice grain ranged from 14.58 – 35.03 kg ha^{-1}.

Urea supergranule (USG) application significantly ($P < 0.05$) increased rice straw nitrogen and phosphorus uptake (Table 4.17) . The highest uptake was observed with USG 2.7g. The increases in nitrogen and phosphorus uptake over USG 1.8 g were 35% and 45% respectively. Phosphorus application was significant ($P < 0.05$) in phosphorus and potassium uptake and the values ranged from 0.15 – 0.38 kg ha^{-1} and from 82.10 – 113.10 kg ha^{-1} respectively. The highest and the lowest P and K uptake were recorded at P_{50} and P_0 respectively. Significant ($P <0.05$) interaction effect was observed with the combination of USG and P on N, P and K total uptake (Table 4.18). The combination of USG 2.7 g and P at 50 kg ha^{-1} was ranked most effective treatment. The values for N, P and K straw uptake were 39.25, 0.46 and 133.00 kg ha^{-1}, respectively.

Table 4.17: Effect of USG and Phosphorus on rice grain and straw uptake during the wet season of 2012.

Treatment	Grain (kg ha^{-1})			Straw (kg ha^{-1})		
	N	P	K	N	P	K
Type of fertilizer						
1.8 USG	58.00	1.32	26.37	23.32	0.22	100.60
2.7 USG	63.10	1.45	25.60	31.57	0.32	103.70
Lsd (5%)	6.10	0.17	3.04	4.18	0.03	15.98
Fpr	0.075	0.080	0.477	0.008	0.002	0.581
Phosphorus rate (kg ha^{-1})						
P_0	36.50	0.73	14.58	24.41	0.15	82.10
P_{20}	57.80	1.25	24.07	25.54	0.20	103.00
P_{30}	66.30	1.70	32.06	26.62	0.30	105.90
P_{40}	67.80	1.73	24.17	29.60	0.32	106.60
P_{50}	74.30	1.52	35.03	31.07	0.38	113.10
Lsd (5%)	10.30	0.23	4.92	5.65	0.06	21.70
Fpr	0.001	0.001	0.001	0.113	0.001	0.068
Fpr USG×P	0.884	0.122	0.001	0.027	0.001	0.006
CV (%)	16.4	15.9	18.3	19.9	21.0	20.6

Table 4.18: Effect of urea supergranule and phosphorus combination on rice straw uptake in the wet season of 2012.

Treatment	N	P	K
		(kg ha^{-1})	
Type of urea × Phosphorus			
USG1.8 × P_0	22.05	0.13	89.50
USG1.8 × P_{20}	26.40	0.20	120.80
USG1.8 × P_{30}	20.25	0.15	109.30
USG1.8 × P_{40}	25.03	0.29	90.10
USG1.8 × P_{50}	22.90	0.30	93.30
USG2.7 × P_0	26.77	0.16	74.60
USG2.7 × P_{20}	24.67	0.20	85.20
USG2.7 × P_{30}	33.00	0.46	102.60
USG2.7 × P_{40}	34.17	0.34	123.10
USG2.7 × P_{50}	39.25	0.46	133.00
Lsd (5%)	7.60	0.08	29.18
CV(%)	19.90	21.00	20.60

4.5.1.1.5 Effect of USG and phosphorus on the agronomic efficiency

Table 4.19 summarizes the effect of USG and phosphorus on AE. Significant difference was observed between the 2 types of USG. The increased in AE using USG 1.8 g over USG 2.7 g was 49%. The combination of USG and phosphorus did not significantly affect the AE but phosphorus levels showed significant effect ($P < 0.05$) on the AE. The AE value ranged from 3.5 to 42.0 kg kg^{-1}. The highest AE was observed at the P_{50} rate that was significantly different from the other treatments.

Table 4.19: Effect of USG and phosphorus on rice agronomic efficiency of nitrogen during the wet season of 2012.

Treatment	Agronomy Efficiency (kg kg^{-1})
Type of urea	
1.8 USG	34.0
2.7 USG	22.8
Lsd (5%)	7.7
Fpr	0.019
Phosphorus rate	
P_0	3.5
P_{20}	26.6
P_{30}	35.9
P_{40}	33.9
P_{50}	42.0
Lsd (5%)	10.20
Fpr	<0.001
Fpr USG × P	0.216
CV (%)	34.8

4.5.1.1.6 Relationship between the agronomic efficiency and grain N uptake

Figure 4.28 shows that the agronomic efficiency (AE) was positively correlated with the grain N uptake ($P < 0.001$). The R^2 values were 0.98 and 0.99 for USG 1.8 g and USG 2.7 g, respectively.

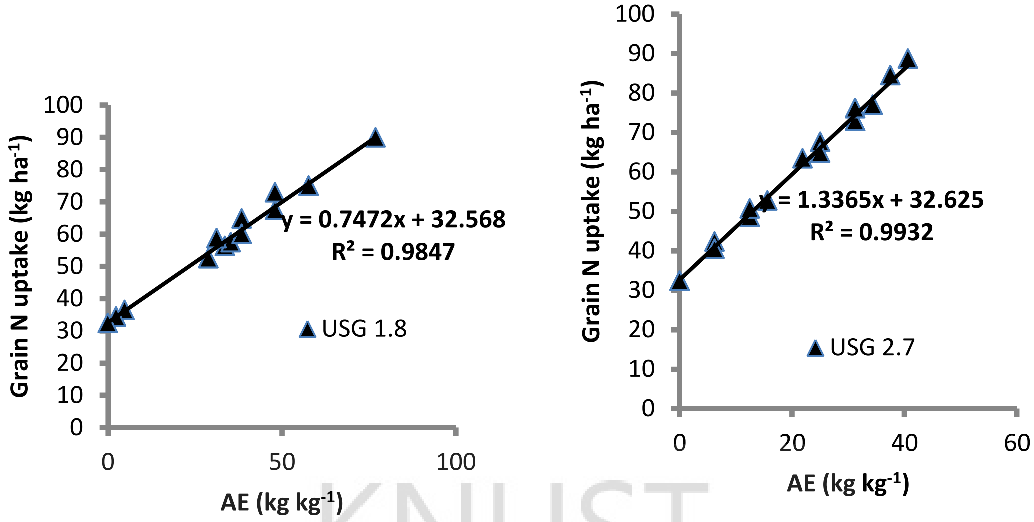


Figure 4.28: Relationship between grain N uptake and AE.

4.5.1.2 Data of the dry season of 2013

4.5.1.2.1 Rice tillers, panicle and thousand seed weight

Table 4.20 summarizes the effect of urea supergranule and phosphorus on number of tillers, panicles and 1000 seed weight. Unlike the wet season of 2012, no significant differences ($P > 0.05$) were observed in the number of tillers and panicles but, yield components were high at the P_{50} rate generally. In contrast, 1000 seed weight was significantly ($P < 0.05$) influenced by the application of USG. The highest and the lowest weight were observed with USG 1.8 g (25.1 g) and USG 2.7 g (24.2 g), respectively.

Table 4.20: Effect of USG and phosphorus on rice tiller, panicle and thousand seed weight.

Treatment	Tillers m^{-2}	Panicle m^{-2}	1000 seed weight (g)
Type of urea			
1.8 USG	227	227	25.1
2.7 USG	238	238	24.2
Lsd (5%)	18	18	0.7
Fpr	0.149	0.149	0.031
Phosphorus rate (kg ha^{-1})			
P_0	234	233	24.3
P_{20}	229	229	24.4
P_{30}	230	230	24.7
P_{40}	228	228	24.5
P_{50}	240	240	25.4
Lsd (5%)	31	31	0.8
Fpr	0.925	0.925	0.067
Fpr USG × P	0.487	0.487	0.833
CV (%)	12.8	12.8	3.2

4.5.1.2.2 Rice grain yield response to USG and different levels of phosphorus

Table 4.21 shows the result of rice grain yields. The highest and the lowest were observed at P_{50} and P_0 respectively. Rice grain yields ranged from 2967 and 4094 kg ha^{-1}. Grain yield at P_{50} was 38% higher than the control (P_0). The increase in grain yield with phosphorus application over the control ranged from 25 - 38%. No significant difference (P > 0.05) was observed with the two levels of USG. Interactive effects were also not significant at P > 0.05.

4.5.1.2.3 Rice straw yield response to USG and different levels of phosphorus during the dry season of 2013.

Table 4.21: Effect of USG and phosphorus on rice grain and straw yield in the dry season of 2013.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Type of urea		
1.8g USG	3502	6496
2.7g USG	3626	7385
Lsd (5%)	861.5	2507.1
Fpr (0.05)	0.679	0.341
Phosphorus rate (kg ha^{-1})		
P_0	2967	6625
P_{20}	3688	6428
P_{30}	3400	7212
P_{40}	3673	6725
P_{50}	4094	7712
Lsd (5%)	367.0	1088.9
Fpr	0.001	0.137
Fpr USG × P	0.133	0.473
CV %	10.0	15.2

Statistical analysis showed no significant difference (P > 0.05) with urea supergranule. However, the highest and the lowest straw yields were observed at P_{50} and P_0 respectively (Table 4.21). The yield at P_{50} was 7712 kg ha^{-1} and the increase over P_0 was 31%. Significant interaction effects were not observed with the combination of USG and phosphorus.

4.5.1.2.4 Grain and straw N, P and K uptake with USG and phosphorus

Tables 4.22 and 4.23 summarize the effect of USG and phosphorus on rice N,P and K uptake. No significant difference was observed with the two sizes of USG on grain N, P and K uptake. However, phosphorus levels significantly ($P<0.05$) affected N, P and K uptake. The N, P and K uptake ranged from 51.1 to 69.0 kg ha^{-1}, 0.96 to 1.68 kg ha^{-1} and 12.9 to 22.56 kg ha^{-1} respectively.

Straw uptake with the two sizes of USG were similar to grain uptake. Statistical analysis did not show significant diference at $P < 0.05$. However, P levels significantly affected N, P and K uptake. The highest P uptake was obtained with P_{50} (1.24 kg ha^{-1}) and the highest N (66.6 kg ha^{-1}) and K (156.9 kg ha^{-1}) uptake occurred on the control plots P_0. Interaction effects were observed between USG and phosphorus applications for N and P uptake. The values of N and P uptake ranged from 39.6 to 71.3 kg ha^{-1} and 0.39 to 1.80 kg ha^{-1} respectively. The highest N and P uptake were obtained with the combination of 1.8 g USG and P_{30} and 2.7 g USG and P_{50}, respectively. No interaction effects were observed with K uptake.

Table 4.22: Effect USG and phosphorus on N,P and K uptake.

Treatment	Grain (kg ha^{-1})			Straw (kg ha^{-1})		
	N	P	K	N	P	K
<u>Type of urea</u>						
1.8g USG	58.0	1.31	18.06	60.1	0.56	139.00
2.7g USG	65.2	1.27	18.05	54.6	0.77	150.30
Lsd (5%)	14.8	0.31	4.68	20.8	0.23	54.10
Fpr	0.22	0.68	0.99	0.47	0.07	0.55
<u>Phosphorus rate kg ha^{-1}</u>						
P_0	51.1	0.96	12.90	66.6	0.50	156.90
P_{20}	64.1	1.32	17.75	61.4	0.45	139.30
P_{30}	61.6	1.22	18.79	57.7	0.56	147.20
P_{40}	62.0	1.26	18.27	41.9	0.57	124.20
P_{50}	69.0	1.68	22.56	59.1	1.24	155.60
Lsd (5%)	6.8	0.30	2.01	9.6	0.12	23.41
Fpr	0.001	0.001	0.001	0.001	0.001	0.048
Fpr USG × P	0.641	0.417	0.001	0.001	0.001	0.408
CV (%)	10.30	10.10	10.80	16.3	17.80	15.70

Table 4.23: Effect of USG and phosphorus combination on rice N, P and K uptake.

Treatment	N	P	K
	(kg ha^{-1})		
Type of urea × Phosphorus			
USG1.8 × P_0	68.4	0.50	142.70
USG1.8 × P_{20}	68.6	0.39	141.10
USG1.8 × P_{30}	71.3	0.64	132.40
USG1.8 × P_{40}	44.2	0.59	122.40
USG1.8 × P_{50}	48.1	0.69	156.30
USG2.7 × P_0	64.9	0.49	171.00
USG2.7 × P_{20}	54.2	0.52	137.50
USG2.7 × P_{30}	44.0	0.48	162.00
USG2.* × P_{40}	39.6	0.56	125.9
USG2.7 × P_{50}	71.1	1.80	154.9
Lsd (5%)	19.84	0.23	51.01
CV(%)	16.3	17.8	22.69

4.5.1.2.5 Effect of USG and phosphorus on the agronomic efficiency

The effect of the combination of USG and different levels of phosphorus on the agronomic efficiency (AE) is summarized in the Tables 4.24 and 4.25. Increasing levels of P significantly affected the AE but differences among the rates (P_{20} and P_{50}) were not significant. Unlike the wet season of 2012, significant difference ($P < 0.05$) was observed between USG and phosphorus. The AE ranged from 8.66 to 34.62 kg kg^{-1}. Phosphorus combined with USG 1.8 g seemed to perform better than USG 2.7 in combination was observed with P.

Table 4.24: Effect of phosphorus on rice nitrogen agronomic efficiency during the dry season of 2013.

Treatment	AE kg kg^{-1}
<u>Type of urea</u>	
1.8g USG	25.00
2.7g USG	17.20
Lsd (5%)	17.52
Fpr	0.252
<u>Phosphorus rate (kg ha^{-1})</u>	
P_0	10.48
P_{20}	23.44
P_{30}	25.12
P_{40}	22.04
P_{50}	24.43
Lsd (5%)	4.77
Fpr	0.001
Fpr USG × P	0.001
CV (%)	21.9

Table 4.25: Effect of USG and phosphorus combination on nitrogen agronomic Efficiency by rice.

Treatments	AE (kg kg^{-1})
Type of urea × Phosphorus	
USG1.8 × P_0	8.66
USG1.8 × P_{20}	31.25
USG1.8 × P_{30}	34.62
USG1.8 × P_{40}	24.28
USG1.8 × P_{50}	26.21
USG2.7 × P_0	12.30
USG2.7 × P_{20}	15.63
USG2.7 × P_{30}	15.63
USG2.7 × P_{40}	19.80
USG2.7 × P_{50}	22.66
Lsd (5%)	16.14
Fpr	<0.001

4.5.1.2.6 Relationship between grain N uptake and the agronomic efficiency

Figure 4.29 indicates that positive relationship was observed between AE and 1.8 g USG and 2.7 g USG. R^2 values with 1.8 g USG and 2.7g USG were 0.76 and 0.78, respectively.

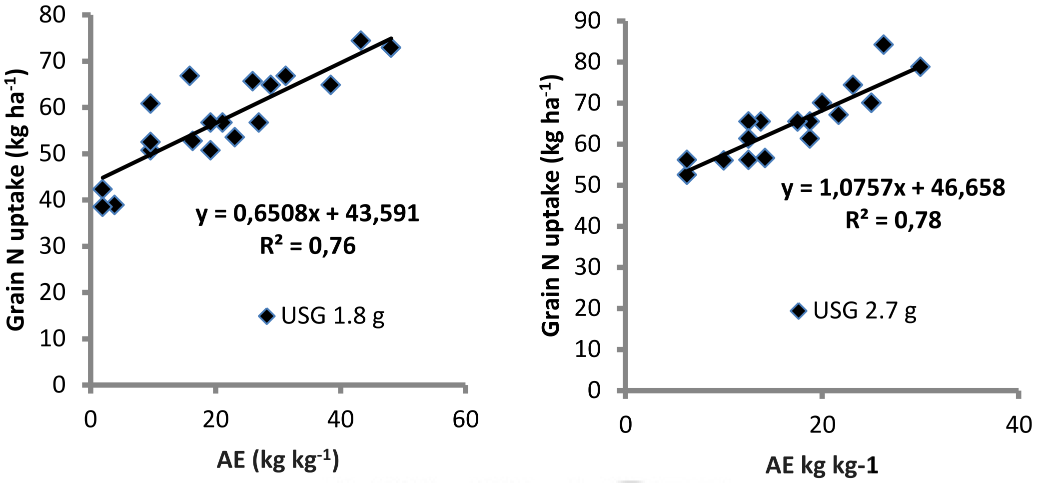


Figure 4.29: Relationship between grain N uptake and AE.

4.5.2 Discussion

4.5.2.1 Effect of USG and phosphorus on N, P and K uptake

Grain N uptake was not significant with the two levels of USG in both seasons. USG 2.7 g increased straw N and P uptake in 2012 and P and K uptake in 2013. These results could be explained by the distribution of the nutrients and thier translocation into grain.

The combination of different levels of N and different levels of P significantly (P <0.05) affected rice plant nutrient uptake during the two cropping seasons. In the cropping season of 2012, the higher level of USG (2.7 g) and phosphorus (P_{50} kg ha^{-1}) gave the highest N, P and K uptake. These results can be explained by the fact that the application of phosphorus and nitrogen had additive beneficial effect on rice uptake and proved superior to nitrogen alone. Nitrogen uptake is related to P uptake (Stroosnijer and Vanderpol, 1982; Yoseftabar, 2012). Devender and Mittra (1985) also reported that the combination of N and P increased rice plant nutrients uptake. Phosphorus content in the plant significantly ($P < 0.05$) increased with phosphorus levels. Khan *et al.,* 2007 reported that phosphorus application to rice increased P accumulation because flooding decreased soil P sorption and increased P diffusion resulting in higher P supply to rice. Flooded soils exhibit a greater capacity to supply plant available phosphorus than non-flooded soils (Dobermann and Fairhurst, 2000). Phosphorus greatly stimulates root development in the young plant, thus increasing its ability to absorb other nutrients from the soil (Dobermann and Fairhurst, 2000).

4.5.2.2 Effect of USG and phosphorus on rice growth parameters

The use of the two levels of USG did not affect rice the number of tillers and panicles. However, the USG at 2.7 g produced the highest number of tillers and panicules during the two seasons. Increased phosphorus levels affected the number of panicles and the number of tillers only in the dry season of 2013. The highest number of tillers and panicles were observed at P_{40}. The thousand seed weights also increased with P levels. This result is supported by the work of Khan *et al.* (2007) who found that the application of P significantly increased yield components of rice. The thousand grain weight increased in the dry season with the increasing level of USG. This result was in agreement with Azam *et al.* (2012) who found that USG 2.7g increased thousnad grain weight more compared to USG 1.8 g.

4.5.2.3 Effect of USG and phosphorus on rice yield

The yield response to the two levels of USG were not significant during the two seasons. These results indicated that the small amount of USG could supply sufficient nutrients to satisfy rice plants' demand for N. This result can also be attributed to the fact that application of higher rates of N fertilizer makes plants susceptible to lodging (Islam *et al.,* 2007). Singh *et al.* (2011) and Murtaza *et al*. (2014) reported that farmers targeting higher yields tend to use higher rates of N. However, such high rates do not always add to the yield. Thus application of N needs to be considered carefully to reduce excessive N losses to the environment and potential contamination issues. Increasing levels of P had significant effect on grain and straw yields. Phosphorus stimulates both root and shoot development and promotes flowering and grain development (De Datta, 1981). Phosphorus is also a component of other compounds necessary for protein synthesis and transfer of genetic material. Phosphorus is a major component in ATP, the molecule that provides "energy" to the plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. In addition, P has been observed to increase root growth and influence early maturity, straw strength, crop quality and disease resistance (Dobermann and Fairhust, 2000). The highest yields were obtained with the P_{50} rate. This can be explained by the fact that P is also one of the limiting nutrients. It can be deduced from the results of the P trials, that application of P to rice becomes apparently significant in as much as the soils of the areas are inherently low in P (Sedogo, 1993). In order to obtain desirable effect on rice performance, additional P input to the native soil P becomes highly important. The results were consistent with the findings of Khan *et al.* (2007), who found that rice yields increased with increasing levels of P (0, 45 and 90 kg P_2O_5 ha^{-1}). Stalon *et al*. (1998) also found that reduced soil conditions created by continuous flood irrigation, generally increase P availability.

4.5.2.4 Agronomic efficiency of rice with different levels of nitrogen and phosphorus

The agronomic efficiency was affected by the two rates of USG. The highest AE was recorded by USG 1.8 g in both seasons and the increases over USG 2.7 g were 49% and 45% in 2012 and 2013 respectively. This result shows by the fact that deep placement of urea can be effective even at small rates (Bandaogo, 2010). The AE and grain N uptake were also positively related. The highest AE were obtained with the P_{50} and P_{30} rates in 2012 and 2013 respectively.

Other nutrients such as P and K, influence the efficient use of N, and N itself exerts a great influence on the efficiency of others. Inadequate supply and thus uptake of one nutrient impairs the efficient use of other nutrients which, are more abundant, and the crop cannot efficiently use the abundant nutrient for plant growth (Janssen *et al*., 1990).

CHAPTER FIVE

5.0 Summary, Conclusions and Recommendations

5.1 Summary

This study focused on the technology of urea deep placement (UDP) of urea supergranule (USG) compared to prilled urea (PU). The results have provided more understanding of the technology in irrigated rice system in Burkina Faso. The results contributed to the general objective of optimizing nitrogen use efficiency (NUE) of irrigated rice by reducing nitrogen losses from the rice field as follows:

i. The concentrations of ammoniun in the floodwater collected ten days after urea application was shown to be high with PU than USG.

ii. The results of the pot experiment on acid and alkaline soils showed that total nitrogen content increased with USG up to the maturity of the rice plant in both soils. Soil total nitrogen was higher with USG compared to PU during the critical growth stages of rice plant. The use of USG also contributed to better root development, plant N, P and K uptake and tiller development in the acid soil compared to the alkaline soil.

iii. On farm field experiment conducted in the two wet seasons and one dry season indicated that the technology of UDP with USG was season dependent. The results showed that rice yields were higher in the dry season, but USG performed better in the wet season. The effect of USG also varied with the two varieties that were used for the study. Rice yields and the nitrogen use efficiency were increased with the rice variety FKR 62N using USG compared to the variety FKR19 in the different seasons. However, USG increased yield components, yield and the AE generally.

iv. The experiments with the two levels of USG and the levels of phosphorus did not show significant interactive effects between nitrogen and phosphorus. Rice yields were not different with the two levels of USG, but the AE was higher with the smaller rate of USG (1.8 g). However, it provided evidence that USG could be efficient even at lower rates. Increasing levels of phosphorus has significantly improved rice yields. Yield response was highest at P_{50}.

5.2 Conclusions

Urea Supergranule is a new technology in Burkina Faso still and is not popular to the farmers.This study has contributed significant knowledge to the understanding of the technology.

i. USG technology was more effective with acid soil than alkaline soil. Pot experiment indicated that soil total nitrogen, plant nitrogen accumulation, root development, the number of tillers were higher in acid soil than alkaline soil. This result confirmed the hypothesis that USG can provide sufficient N in a single application to satisfy the plant's needs and increase plant nitrogen uptake and also confirmed that the performance of USG is greater in acid soil compared to PU.

ii. The use of USG reduced ammonium accumulation in the floodwater by 18 to 37% relative to the application of PU. Highest value of floodwater ammonium was observed with PU confirming the hypothesis that USG technology can reduce N accumulation in floodwater and thereby limit N losses in floodwater.

iii. The results clearly of this study demonstrated that urea deep placement with USG can increase rice grain yield, N uptake and the nitrogen use efficiency. However, the efficiency of USG differed with the two rice varieties. Rice variety FKR62N produced higher yields with USG than FKR19. These results confirmed the hypothesis of this study that deep placement of USG could be an effective strategy for increasing rice yields.

iv. The combination of USG and increasing phosphorus levels was not significant. Phosphorus levels increased the AE and rice straw and grain yields.

This study suggests that farmers may derive more benefit from the use of USG technology than broadcasting urea which leads to high N losses. Urea super granule can be used by farmers to improve nitrogen use efficiency and increase grain yields in the irrigated rice cropping system. The study clearly demonstrated that USG used at the rate of 1.8 g/4 hills especially with rice variety FKR 62N increases rice yield in irrigated systems in Burkina Faso and 50 kg P/ha can be effectively used with USG1.8 g/ 4 hills for irrigated rice cultivation especially in wet season. Urea supergranule is a promising technology that can be adopted by West African smallholder farmers, particularly for those in irrigated areas.

5.3 Recommendations

i. This study needs to be carried out t in a wide range of agroecologies to establish a wider applicability and adaptability of the USG technology.

ii. Further studies should be conducted to appraise the cost effectiveness of the USG technology.

iii. As Urea deep placement is a new technology, there is a need to train more extensions agents for its promotion.

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APPENDICES

Appendix 1: ANOVA of total N uptake in pot experiment

Growth stage		Nitrogen uptake		
		MS	df	Fpr
Tillering	Urea fertilizers	0.062	2	0.001
	Soil type	0.185	1	0.001
	Urea fertilizer x soil type	0.073	2	0.001
Panicle initiation	Urea fertilizer	1.530	2	0.001
	Soil type	0.147	1	0.009
	Urea fertilizer x soil type	0.242	2	0.001
Flowering	Urea fertilizer	5.001	2	0.001
	Soil type	0.190	1	0.101
	Urea fertilizer x soil type	0.093	2	0.259
Maturity	Urea fertilizer	0.121	2	0.001
	Soil type	0.012	1	0.117
	Urea fertilizer x soil type	0.026	2	0.014
Growth stage x urea fertilizer x soil type		0.101	6	0.008

Appendix 2: ANOVA of total P uptake in pot experiment

Growth stage		Phosphorus uptake		
		MS	df	Fpr
Tillering	Urea fertilizers	0.001	2	0.001
	Soil type	0.000	1	0.476
	Urea fertilizer x soil type	0.005	2	0.001
Panicle initiation	Urea fertilizers	0.148	2	0.001
	Soil type	0.057	1	0.001
	Urea fertilizer x soil type	0.241	2	0.001
Flowering	Urea fertilizers	0.313	2	0.003
	Soil type	0.147	1	0.001
	Urea fertilizer x soil type	0.058	2	0.001
Maturity	Urea fertilizers	0.011	2	0.001
	Soil type	0.012	1	0.001
	Urea fertilizer x soil type	0.0003	2	0.545
Growth stage x urea fertilizer x soil type		0.014	6	0.001

Appendix 3: ANOVA of total K uptake in pot experiment

Growth stage		Potassium uptake		
		MS	df	Fpr
Tillering	Urea fertilizers	2.680	2	0.001
	Soil type	12.204	1	0.001
	Urea fertilizer x soil type	1.688	2	0.231
Panicle initiation	Urea fertilizers	1.747	2	0.001
	Soil type	2.261	1	0.001
	Urea fertilizer x soil type	0.221	2	0.009
Flowering	Urea fertilizers	8.153	2	0.001
	Soil type	11.896	1	0.001
	Urea fertilizer x soil type	2.670	2	0.001
Maturity	Urea fertilizers	0.740	2	0.002
	Soil type	9.134	1	0.001
	Urea fertilizer x soil type	0.425	2	0.018
Growth stage x urea fertilizer x soil type		0.333	6	0.023

Appendix 4: ANOVA of root weight

Growth stage		Root weight		
		MS	df	Fpr
Tillering	Urea fertilizers	29.36	2	0.011
	Soil type	36.754	1	0.014
	Urea fertilizer x soil type	0.07	2	0.985
Panicle initiation	Urea fertilizers	787.31	2	0.001
	Soil type	154.530	1	0.161
	Urea fertilizer x soil type	8.24	2	0.891
Flowering	Urea fertilizers	812.06	2	0.001
	Soil type	477.04	1	0.011
	Urea fertilizer x soil type	18.54	2	0.727
Maturity	Urea fertilizers	332.00	2	0.169
	Soil type	7640.50	1	0.001
	Urea fertilizer x soil type	370.00	2	0.142

Appendix 5: ANOVA of number of tiller in pot experiment

Growth stage		Number of tillers		
		MS	df	Fpr
Tillering	Urea fertilizers	96.67	2	0.001
	Soil type	170.667	1	0.001
	Urea fertilizer x soil type	17.67	2	0.017
Panicle initiation	Urea fertilizers	602.38	2	0.001
	Soil type	433.50	1	0.001
	Urea fertilizer x soil type	37.63	2	0.104
Flowering	Urea fertilizers	1099.04	2	0.001
	Soil type	477.04	1	0.001
	Urea fertilizer x soil type	88.29	2	0.001
Maturity	Urea fertilizers	787.62	2	0.001
	Soil type	2480.04	1	0.001
	Urea fertilizer x soil type	100.40	2	0.197
Growth stage x urea fertilizer x soil type		79.19	6	0.02

Appendix 6: ANOVA of soil N content in pot experiment

Growth stage		Soil N content		
		MS	df	Fpr
Panicle initiation	Urea fertilizers	0.002	2	0.001
	Soil type	0.000	1	0.001
	Urea fertilizer x soil type	0.004	2	0.001
Flowering	Urea fertilizers	0.004	2	0.001
	Soil type	0.017	1	0.001
	Urea fertilizer x soil type	0.003	2	0.001
Maturity	Urea fertilizers	0.001	2	0.762
	Soil type	0.004	1	0.019
	Urea fertilizer x soil type	0.003	2	0.023
Growth stage x urea fertilizer x soil type		0.003	4	0.001